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Summary Report

on

MARK I DEEP DIVE SYSTEM (DDS-I) HANDLING STUDY  
PHASE I - CONCEPTUAL DESIGN

to

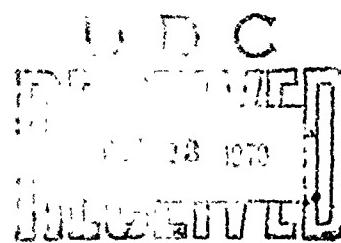
NAVAL SHIP ENGINEERING CENTER  
Contract No. N-0014-70C-0072

by

D. C. Doerschuk, D. E. Adkins, and J. S. Glasgow

October 1, 1970

BATTELLE MEMORIAL INSTITUTE  
Columbus Laboratories  
505 King Avenue  
Columbus, Ohio 43201



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MARK I DEEP DIVE SYSTEM (DDS-I) HANDLING STUDY  
PHASE I - CONCEPTUAL DESIGN

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ABSTRACT

*This report covers selection of an optimal concept for handling the Mark I Deep Dive System's Personnel Transfer Capsule, in a Sea State 3, from ATS, ASR, and ARS Class ships. Included are descriptions of some of the many possible handling system concepts generated by idea conferences and a literature search. The more feasible concepts are analyzed and compared using a set of eleven comparison factors. The optimal system, an articulated telescoping crane, is chosen according to its overall performance on the comparison factors.*

INTRODUCTION

The U. S. Navy Mark I Deep Dive System (DDS-I) represents a synthesis of recent equipment developments to support saturated diving to greater depths. However, a handling system has not yet been developed that would enable the DDS-I to be deployed under the wind and sea conditions for which it was designed. This report covers a program in which methods and equipment were conceived for deployment and recovery of the DDS-I Personnel Transfer Capsule (PTC) aboard ASR, ARS, and ATS class ships in Sea State 3.

The complete deployment of the PTC commences when it is removed from its stowage position to be transferred to its mated condition on the DDS-I Entrance Lock (EL). Deployment terminates when the PTC is totally submerged in the sea and the handling system is detached and returned aboard the ship. Recovery commences when the PTC begins its ascent, at which time the handling system is made ready to receive the PTC near the surface and smoothly transfer it to its mated position on the EL. Recovery terminates when the PTC is restored to its stowage position.

In this program, handling-system concepts were to be developed for open-sea deployment and recovery of the PTC from each class ship. The systems were to provide satisfactory and safe operation during Sea State 3 ship motions as specified by the Naval Ship Engineering Center. The handling systems were to be capable of extending the PTC over the side of the ship in such manner that uncontrolled physical contact between ship and the PTC does not occur. Also the systems were to provide sufficient rotational orientation of the PTC about its vertical axis to permit alignment and mating with the EL.

Since the DDS-I was designed to be completely portable, air transportable, and readily installed and removed from the support ship, only those handling-system designs complying with this requirement were considered. The handling system was to be another component of the DDS-I to be stored with the rest of the system when not in use.

Major DDS-I components that were to be arranged on the ship decks along with the handling systems include:

- (1) Deck Decompression Complex (DDC)
- (2) Main Control Console (MCC)
- (3) Power Control Console (PCC)
- (4) Life Support Package (LSP)
- (5) Strength Power and Communications Cable (SPCC) and SPCC Winch.

#### SUMMARY

The first step in obtaining a feasible handling-system concept was to generate any and all possibly applicable concepts. Then the feasibility of each was measured and the more desirable chosen. To determine any and all possibly applicable concepts, ideas were generated in special idea conferences and gathered in literature, patent, and manufacturer searches. Also, submersible operators were interrogated through a questionnaire that concerned various facets of the handling operation and its problems.

The literature gathered during the concept-generation process served two other major purposes. It provided a good indication of the present state of the art in submersible handling and it aided in analysis of the Mark I handling problem and in basic design of the more feasible handling systems. At the end of the project all information gathered was indexed, cross referenced, then incorporated into the Navy-Battelle Diver Equipment Information Center (DEIC). This information is listed in order of DEIC accession number and also is cross referenced by clue word in Appendix A.

Concurrent with the concept-generation process, the basic requirements of a handling system were determined. After all the various concepts and ideas were recorded, each system and its notable aspects were evaluated. Some overall systems appeared unfeasible, but a particular aspect looked useful. These aspects were noted and later considered along with the feasible concepts in a dissection and synthesis process that culminated in the selection of four systems for further analysis. These systems were:

- (1) Articulated telescoping crane for ATS class ships
- (2) A-frame on rails with dual-mode pendant for ATS class ships
- (3) Articulated telescoping crane for ASR/ARS class ships
- (4) A-frame with dual-mode pendant for ASR/ARS class ships.

At the request of the Navy, a fifth system was considered along with those already judged feasible. This system was the type currently being used aboard the ARS-38 (USNS Gear), which consisted of four tugger booms with corresponding snubber lines.

Once the potentially feasible types of systems had been determined, preparation for effective analysis and basic design of each was begun. This preparation was a quantification of salient design parameters that included optimum handling path, cable loading for different paths and conditions, and available deck area and layout. Once these parameters were quantified, it was possible to execute a basic design for each system such that its weight, size, center of gravity, manning requirements, power requirements, and transportability could be determined.

The final step in determining the most feasible handling system for each of the ship classes was to evaluate and compare each system on certain selected factors. Appropriate weights were given to each factor such that a total score would represent relative system feasibility.

Others may consider specific factors to be more or less important than do the authors of this report. If so, the factor weights can be changed accordingly and system feasibility may be altered.

The following factors and their respective weights were used in determining system feasibility:

<u>Factor</u>	<u>Weight</u>
Weight	3
Size	3
Ease of operation	3
Effect on ship stability	3
Commonality with other ships classes	3
Safety	3
Power requirements	2
Transportability	2
Cost	2
Ease of installation	2
Manning requirements	1

### CONCLUSIONS

- (1) For ATS class ships, the most feasible handling system is the Articulated Telescoping Crane.
- (2) For ASR/ARS class ships the most feasible handling system is the Articulated Telescoping Crane.

- (3) Use of the ship's main salvage winch, instead of a separate constant-tension winch, for the A-frame system on ASR/ARS class ships, if practical, would reduce system weight from 36,600 to 12,600 pounds.
- (4) In a Sea State 1 or less, the most feasible system is the Four-Tugger Winch-Boom system presently being used aboard the ARS 38 Gear.

On both ATS and ASR/ARS class ships the Articulated Telescoping Crane (ATC) handling system scores highest in feasibility. For ATS class ships the ATC system scored 26.64 in relative feasibility as opposed to the A-frame on Rails system score of 17.88. In ASR/ARS class ships the ATC system scored 25.20 in relative feasibility as opposed to the A-frame system score of 18.88.

As previously discussed, the feasibility scores are contingent upon the assigned comparison factor weights. In the ATS class, only a drastic reassignment of factor weights (in favor of weight, effect on ship stability, power requirements, and cost) would result in the A-Frame on Rails scoring higher than the ATC in feasibility.

Similarly, in the ASR/ARS class ships, only a drastic reassignment of factor weights (in favor of weight, and cost) would result in a higher score for A-frame over ATC. However, if a detailed dynamics analysis demonstrated use of the ship's main salvage winch in conjunction with the A-frame to be practical, then a constant-tension winch would not be required for that system. This would reduce system weight from 36,600 pounds to 12,600 pounds, which may make the system particularly appealing to some parties.

The Four-Tugger Winch-Boom system was not considered in the system comparison as it is not designed for use in Sea State 3. The systems compared were all designed for Sea State 3 and, therefore, had considerably higher weights, sizes, effects on stability, and cost. Scoring the Four-Tugger Winch-Boom system would have only yielded a meaningless score. However, the system could have been compared along with the others for use in a Sea State 1, its original design environment. If this is done the Four-Tugger Winch-Boom system easily outscores the other systems and would, therefore, be the most feasible for Sea State 1 operation.

#### RECOMMENDATIONS

It is recommended that:

- (1) An Articulated Telescoping Crane be designed and fabricated for handling the MkI PTC aboard any of the ATS, ASR, or ARS class ships. The next step in designing the system would be continuation of the three-phase design program. Phase II - Preliminary Design Analysis, would cover development of guidance drawings, and a complete comprehensive engineering analysis of the system. Phase III - Final Design, would cover finalizing the complete design package, including specifications and working drawings.

- (2) If the possibility of a 12,600-lb A-Frame handling system is particularly appealing, an analysis to determine practicality of using the ship's main salvage winch, instead of a separate constant-tension winch, for the A-Frame system aboard ASR/ARS class ships should be executed.
- (3) For handling the MKI PTC in a Sea State 1 or less, the existing Tugger-Boom system should be used.

## ENGINEERING ACTIVITY

Engineering activity concentrated on three areas - generation, analysis, and comparison of feasible handling systems. The output of the generation process was four feasible handling systems; the outputs of the analysis process were basic designs and engineering analyses of the feasible systems; the output of the comparison process was the selection of an optimal handling system for use aboard each ship class, based on eleven comparison factors.

### Generation of Feasible Handling Systems

Literature, patent, and manufacturer searches, contacts with submersible operators, and idea conferences served as sources of possible handling-system concepts. Concepts listed in the "Possible Handling-System Concepts" section represent the useful output of the searches and conferences. Numerous other concepts were screened and immediately rejected due to obvious impracticality.

#### Literature Search

Five sources were used:

- (1) Defense Documentation Center
- (2) Smithsonian Institution, Science Information Exchange
- (3) NASA Scientific and Technical Information Facility
- (4) Engineering Index, years 1960 to present
- (5) Diver Equipment Information Center (DEIC)

Specialists at each source, using a list of clue words, retrieved abstracts of possibly applicable articles. Over 1000 abstracts from the four facilities were forwarded for examination. From these, 49 pertinent articles and reports were ordered, read, used, and incorporated into DEIC. Useful references are listed in Appendix A of this report.

#### Patent Search

Patent specialists conducted a search for novel and/or possibly applicable ideas dating from 1900 to present. Of these, 85 applicable patents were identified and incorporated into DEIC.

#### Manufacturers Search

Manufacturers of handling equipment that could possibly be used in shipboard deployment and recovery of submersibles were contacted. Fifty-nine of these were found

to be manufacturers of applicable handling equipment. Catalogs, drawings, and information from these companies were incorporated into DEIC. The companies are listed in Appendix A.

#### Submersible-Operators Questionnaire

Forms were sent to 18 operators, and 11 responded. Questions concerned type of support ship, deployment and recovery sea states, the handling system, and motion compensation. A copy of the questionnaire, a list of operators, and a summary of the responses appear in Appendix B.

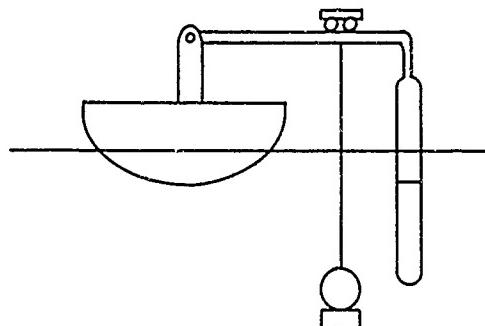
#### Idea Conferences

Fourteen creative and knowledgeable engineers, scientists, and others with relevant experience were asked to formulate and discuss novel solutions to the handling problem during a series of four idea conferences. Although many of the concepts generated during these meetings were beyond the state of the art or were impractical, some appeared quite feasible.

#### Possible Handling-System Concepts

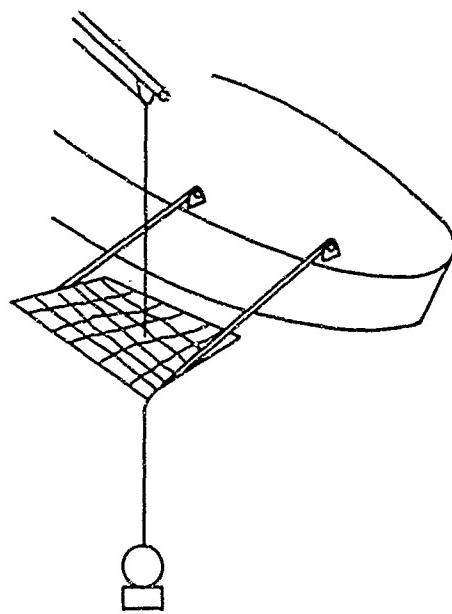
Spar Buoy With Trolley. This system provides a gradual transition from the underwater motion of the PTC to the motion of the ship. The spar-buoy end of the trolley is stable, while the pinned end is fixed relative to the ship. Deployment and recovery of the PTC takes place far out on the arm next to the buoy. The PTC travels to and from this point above water using an electric or hydraulic trolley.

The concept is simple and appears workable. However size and weight of the spar buoy and arm are formidable when consideration is given to the weight of the PTC. Weight of the PTC, spar buoy, and arm totals over 25,000 lb, therefore at least 390-ft<sup>3</sup> displacement must be designed into the system such that it can be taken up without drastically changing the vertical position of the spar buoy. Using a 5-ft-diameter spar buoy, recovery of the PTC from the water would cause a 20-ft drop in spar-buoy vertical position. Obviously then a major drawback with this concept is sheer magnitude. Transportability, stowage, and deployment of a buoy at least 5 ft in diameter and long enough to attenuate the maximum wave height would pose severe problems. For these reasons this concept was considered unfeasible. However, the idea of gradual transferal to ship motion was retained and used during later synthesis and dissection of concepts.



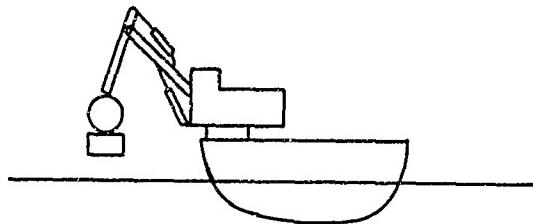
Rope-Net Catch. The simplest concept in which the principle of pulling the PTC snug against a member fixed relative to the ship manifested itself in the rope-net catch concept.

Two or three outriggers are used to lay a large rope net on the ocean surface. A strength cable is then threaded through the center of the net and used to pull the PTC up into it. Once caught in the net the weight of the outriggers keep a taunt downward pull on the PTC and prevent undesired motion as the PTC is removed from the sea. The strength cable (which would be supplementing the SPCC) is reeved through a sheave on the ships boom.

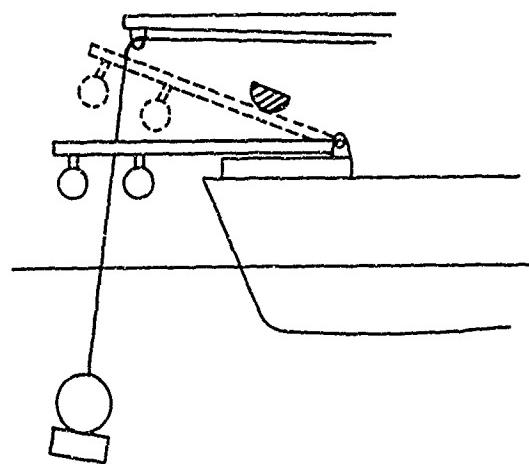
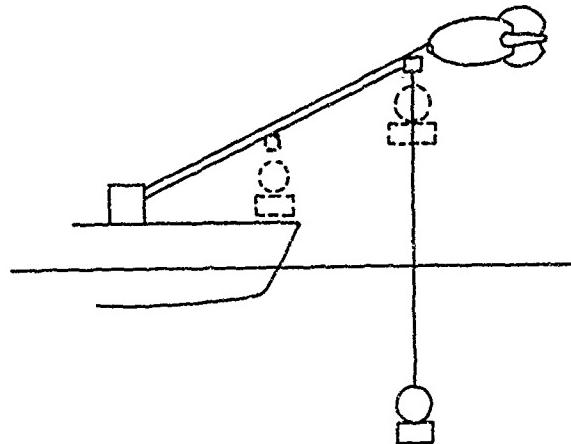


The major problem with this concept is the inherent untidiness and unpredictability of the net. Also, fragile appendages on the PTC could easily be damaged. This idea was therefore considered unfeasible.

Articulated Crane. Articulated cranes are in widespread submersible handling use. A review of commercial hydraulic hoists such as the Link Belt LS-5000 and the Insley H-2000 showed that cranes with 20,000-lb capacity at 15-ft horizontal reach are presently available. The articulated crane appears to be quite capable of picking up the PTC from the EL or stowage position and carrying it to a point of deployment somewhere below the surface. This operation is reversed for recovery. However, there are two obvious disadvantages to this concept. One is the 40,000 to 60,000-lb weight of the system. Also, there are no provisions in the commercially available units for damping or eliminating undesired sea motion. This concept was considered feasible but it was understood that due consideration must be given to the two difficulties.

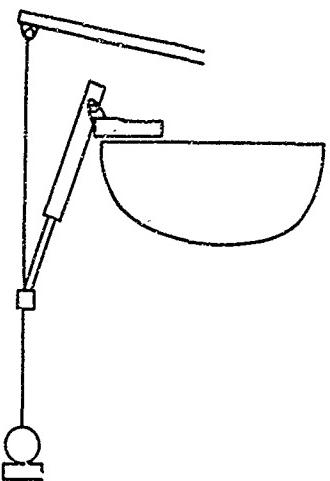


Balloon Assist. The Balloon assist is a variation on the "gradual change from stable to ship-motion" theme. Recovery and deployment take place from a winch riding the tether of a relatively stable balloon towed by the ship. Once the PTC is pulled completely out of the water during recovery, the winch is wound down onto the ship and the PTC is stowed. Major drawbacks making this concept unfeasible are the possibilities of wind direction change, requirement of at least 315,000 SCF of helium for the balloon, and the balloon handling, maintenance, and manning problems.



Quick Snatch. This concept employs a shock-absorbing collar such that the PTC can be quickly removed from the sea. As the PTC passes thru the air-sea interface it contacts the absorbing collar which is attached to an arm that moves upwards to a restraint. The pivot of the arm is set on a rotating table that allows the entire package to rotate the PTC over a stowage point or EL.

This concept was considered feasible. During the dissection and synthesis process the idea of pulling the PTC against a shock-absorbing device until it is fixed to the ship manifested itself in the telescoping articulated crane system, one of the systems chosen for analysis.



Telescoping Cylinder. This concept employs a hydraulic cylinder with two modes of operation - normal push-pull power; and damping, controlled by variable orifices. The SPCC cable leads through an attachment at the end of the cylinder that provides automatic latching. The cylinder is powered about its horizontal axis by a rotary actuator or gears, with the entire unit on a turntable.

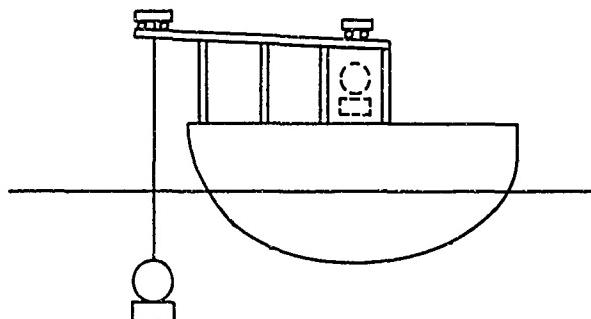
Deployment commences by positioning the attachment on the cylinder end over the PTC which is in a stowage position over the EL. Hookup is made and the PTC is moved overboard and into the ocean. At some point below the surface the hookup is released and the PTC is lowered by the SPCC, which leads through the attachment device. Recovery commences by pulling the SPCC in until the

PTC latches onto the attachment device, at which time the cylinder is in its damping mode, preventing undesired ship motion from resulting in damaging dynamic loads. Once the PTC is attached the cylinder is switched to power mode and the PTC is raised from the sea and set on the EL.

An alternative to leading the SPCC through the attachment device is the use of a cable for deployment and recovery only. The SPCC would not be lead through the attachment device. The auxiliary cable acts exactly as the SPCC did in the previous description but is removed once it is payed out to 10 or 20 feet. For recovery, the SPCC pulls the PTC near the attachment device, then the auxiliary cable is attached and used to pull the PTC home into the attachment device. With an auxiliary cable, the telescoping-cylinder handling system does not have to remain in the sea during undersea PTC operations.

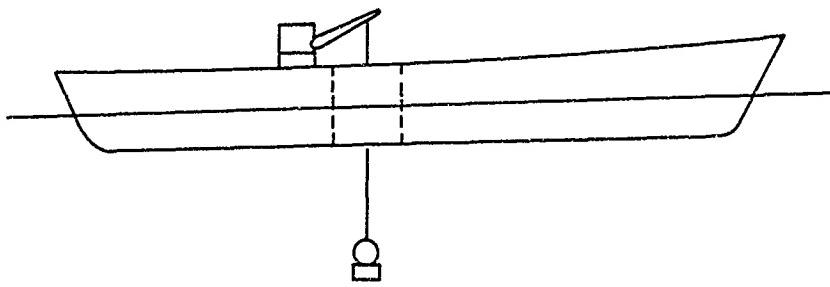
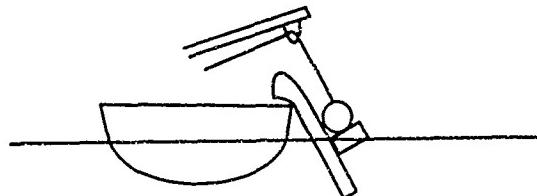
The major problem with the dual-mode telescoping cylinder is the bending stress induced when it is extended and carrying the weight of the PTC to the EL. The moment arm would be at least 15 feet, which would mean bending moments of 15 feet x 20,000 lb or 300,000 ft-lb. As design of a cylinder to handle such loads would be difficult, this concept was considered unfeasible. However, a dual-mode hydraulic cylinder was used as a component on one of the systems considered for further analysis.

Overhead Crane. An overhead crane between the EL and the point of deployment/recovery is an obvious approach to the handling problem. An electric trolley is mounted on rails and leads the SPCC or auxiliary cable to the PTC. Deployment and recovery takes place from the end of the crane overhanging the sea. The electric trolley provides topside travel between the overhang and the EL.



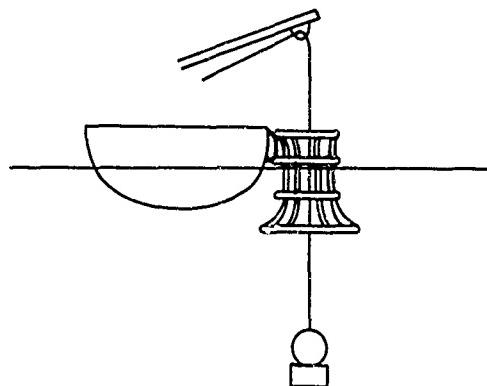
Unfortunately, there are no provisions for damping undesired motion during deployment and recovery. Also, a high-center-of-gravity superstructure is required along the entire topside path of the PTC. For these reasons this system was considered unfeasible.

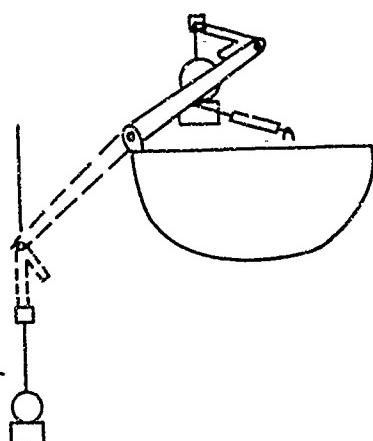
Inflatable Ramp. In this concept, an inflatable rubber ramp is suspended over the side of the ship. The PTC is lowered and raised using the ramp as a guide and the ship's boom as support. Stowage and weight problems would be practically nonexistent. However, the idea is too simplistic in that the configuration of the PTC does not lend itself to be easily guided by a simple ramp. Vertical orientation would be difficult to maintain, and fragile exterior equipment would be prone to damage. This concept was considered unfeasible.



Centerwell. Deployment and recovery through a hole in the ship near the intersection of the roll and pitch axes may greatly reduce undesired motion. However, this concept is not applicable to the U. S. Navy ships and other possible ships of opportunity being considered.

Guiding Chute. In this concept, a cage acting as a guiding chute is deployed over the side of the ship. The PTC is raised and lowered through it using a series of guide shoes attached to the PTC. Lift is provided by the ship's boom. The probability of dangerous impact loads between PTC and cage as the PTC is first drawn to the chute during recovery make this concept unfeasible.





A-Frame. This is one of the simplest concepts considered. The PTC is transferred between the EL and the deployment/recovery point by a simple A frame hinged near the deck of the ship and powered by hydraulic cylinders. The SPCC or an auxiliary lifting cable passes through a fairlead at the apex of the A-frame. The A-frame is designed such that its two extreme positions are the EL and the deployment/recovery point.

A problem with this concept is the difficulty of achieving a combination of geometry and hinge-axis location that gives proper EL and deployment/recovery positions. Another

problem is possible impact loading at pickup due to undesired motion. These problems can be overcome by an addition to the A-frame. A pendant or added arm on the apex gives designers an added dimension to achieve proper hinge-axis location. At the same time, this pendant can be attached such that it swings free when the A-frame is overboard and is fixed when the A-frame is raised. This feature reduces impact loading at pickup by providing an extra degree of freedom. The A-frame with pendant concept was considered feasible and emerged intact from the dissection and synthesis process as a system to be further analyzed.

#### Analysis of Feasible Handling Systems

The purpose of analyzing and preparing a basic design of the feasible handling systems was to allow an estimate to be made on performance of each system with respect to eleven comparison factors. Basic design of each system was based on the requirements and environment as determined by optimum handling path of PTC, cable loading for different paths and conditions, and available deck area and layout. The scope of the design work was limited to comparing the systems on the eleven factors. Other design work such as sizing of smaller system components, or cable selection was considered extraneous to the objective and therefore not performed.

#### Consolidation of ASR & ARS Class Ships

When the optimal handling paths, cable loads, and deck areas were being determined for the ATS, ASR, and ARS class ships, it became apparent that the ATS class ship is quite different than the two others in these respects. However, the ASR and ARS are very similar. Figure 1 shows a comparison of ship cross sections at likely EL locations. The ASR and ARS class ships are of a much narrower beam than the ATS class ships. The ASR is narrowest. Figure 2 shows the aft-deck outline of the three ships. Again, the ATS is much larger than the similar ASR and ARS class ships. The ASR has least available deck space. For Sea State 3, the ASR and ARS roll 5.5 and 5.8 degrees, respectively, while the ATS rolls 5.0 degrees; the ASR and ARS pitch 2.6 and 2.7, respectively, while the ATS pitches 2.0 degrees.

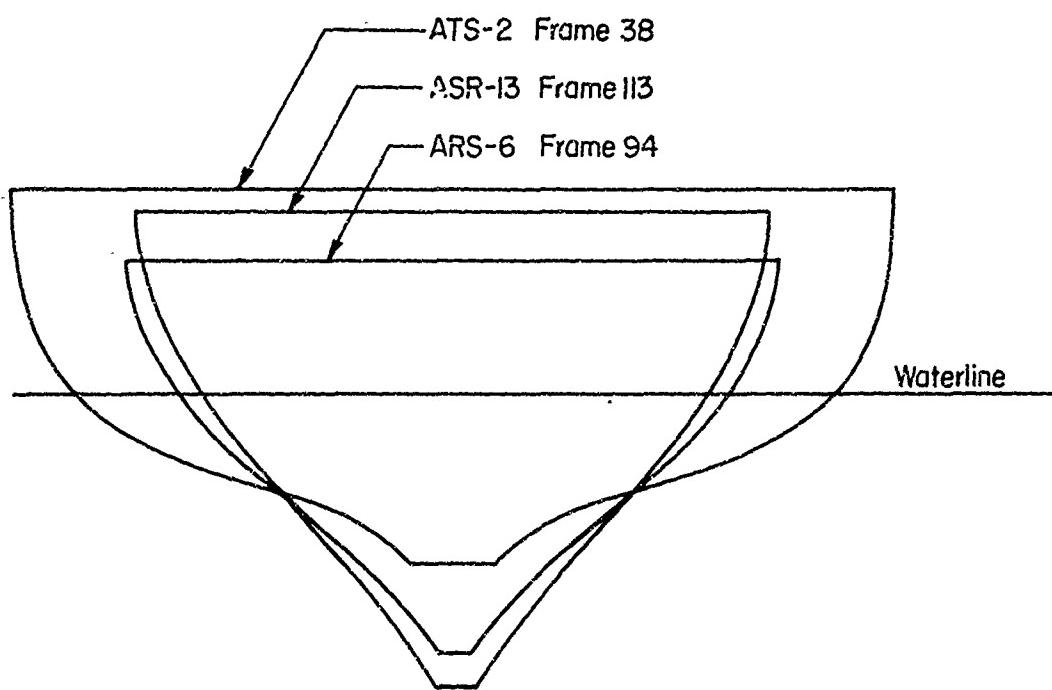


FIGURE 1. SHIP CROSS SECTION AT LIKELY EL LOCATION

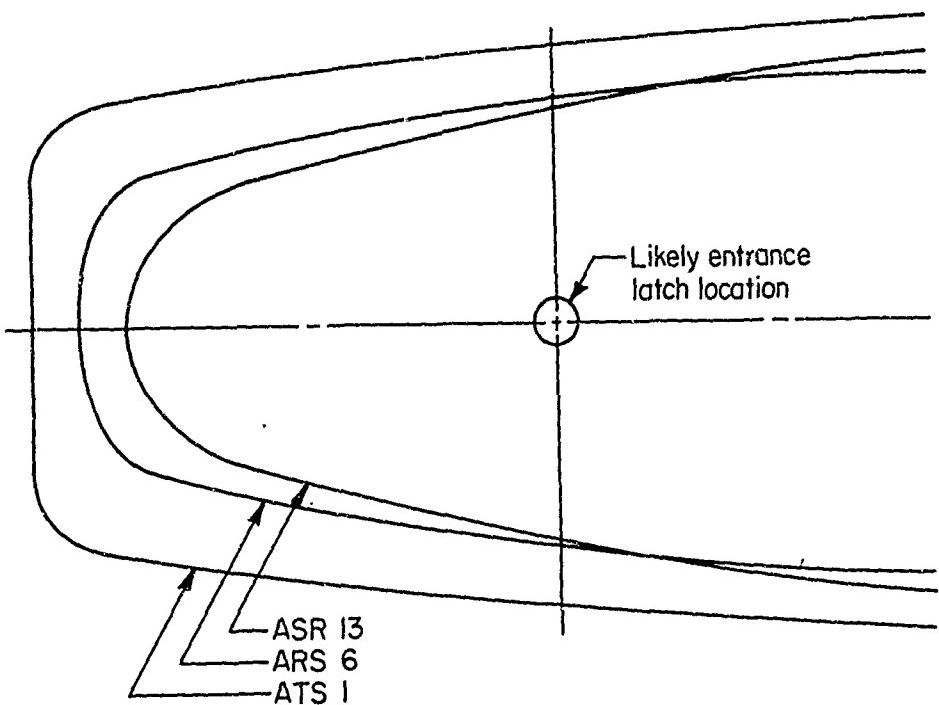


FIGURE 2. AFT-DECK OUTLINE

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To avoid duplication of effort, it was decided to treat the ASR and ARS class ships as one case and the ATS class ships as a second. The ASR and ARS are so similar that the optimal handling system would be the same for both classes. Since the ASR is slightly smaller in deck layout and beam at the likely EL location it poses a more difficult design problem. It was therefore chosen as the design case to represent the ASR/ARS class ships. The ASR 13 and ATS 1 were selected as specific design cases to represent the ASR/ARS and ATS class ships, respectively.

#### Quantification of Salient Design Parameters

Optimum Handling Paths. The most basic requirement of the handling systems is to move the PTC through some path between the EL and the point of deployment/recovery. The optimal path was determined for both stern and side deployment for ATS and ASR/ARS class ships, making a total of four paths. Path optimality was determined in each case by EL and deployment/recovery-point location, and the area of an outline swept by the FTC in its worst possible swing. First, the EL and deployment/recovery locations were noted on ship drawings. Then, the PTC swing outline was moved between these locations in a path as close as possible to the ship to minimize dynamic forces which are proportional to distance from the roll and pitch axes. The line traced by the padeye at the top of the PTC was drawn.

In each case, the area of the PTC swing outline was determined by swinging the PTC on its padeye  $\pm 3.0$  times the roll or pitch angle amplitude, depending on whether the concern was for side or stern deployment/recovery. Also, in each case the PTC swing outline cleared the bulwark by two feet.

The ASR/ARS stern-deployment path shown in Figure 3, lies along the centerline of the ship. The point of deployment/recovery lies six feet from the aftmost protuberance of the ship and 136 feet from the pitch axis.

The ASR/ARS side-deployment path shown in Figure 4 lies at Frame 113. This frame was chosen as the most likely EL location; it is the same distance forward of the stern, 37 feet, that the EL was on the ARS 38 USNS "Gear" when the MKI system was being used on that ship. Deployment/recovery point is 7.5 feet from the side of the ship and 24 feet from the roll axis.

The ATS stern-deployment path shown in Figure 5 lies along the centerline of the ship. Point of deployment/recovery lies 5.5 feet from the aftmost protuberance of the ship and 137.5 feet from the pitch axis.

The ATS side-deployment path shown in Figure 6 lies at the Frame 38. This frame is the location of the EL in the Hold 4 and is 87 feet from the pitch axis. The deployment/recovery point is 7.5 feet from the side of the ship and 31 feet from the roll axis.

Ship Motion and Cable Loading Along Optimal Paths. The optimal handling paths provided a good approximation of the paths along which the PTC would be moved by the possible systems. The next step was to determine the ship motions and cable loads along this path.

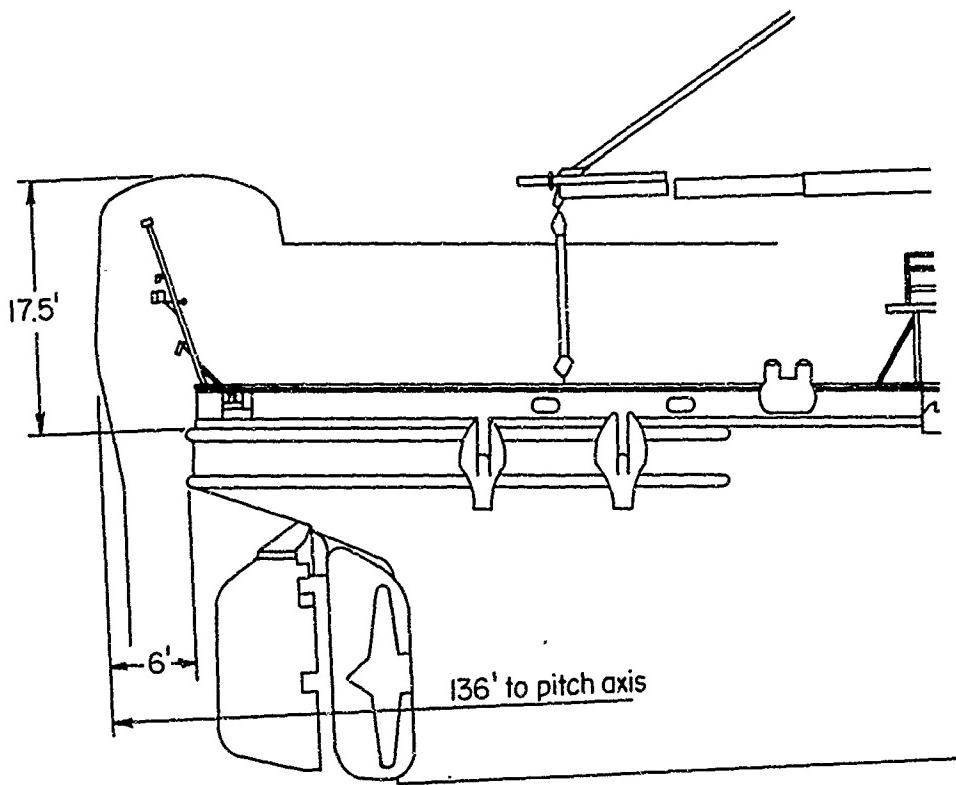


FIGURE 3. ASR/ARS STERN-DEPLOYMENT PATH

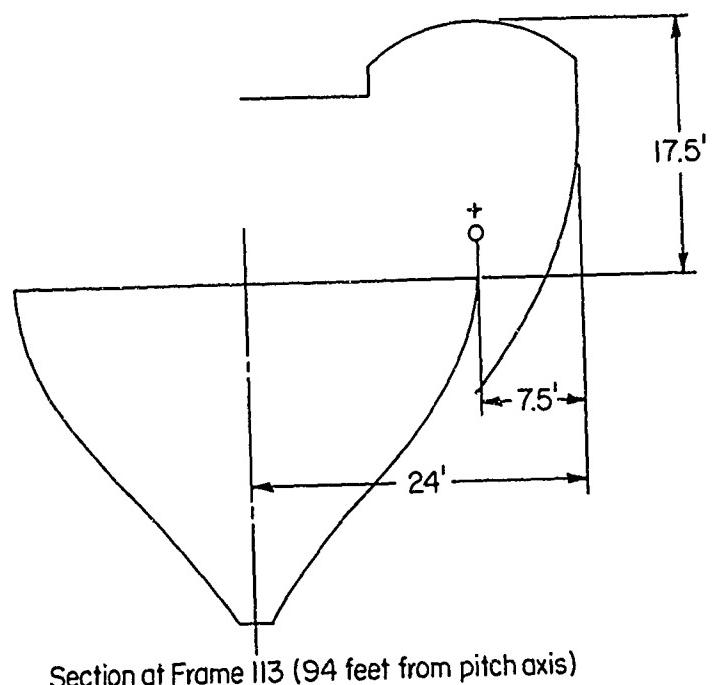


FIGURE 4. ASR/ARS SIDE-DEPLOYMENT PATH

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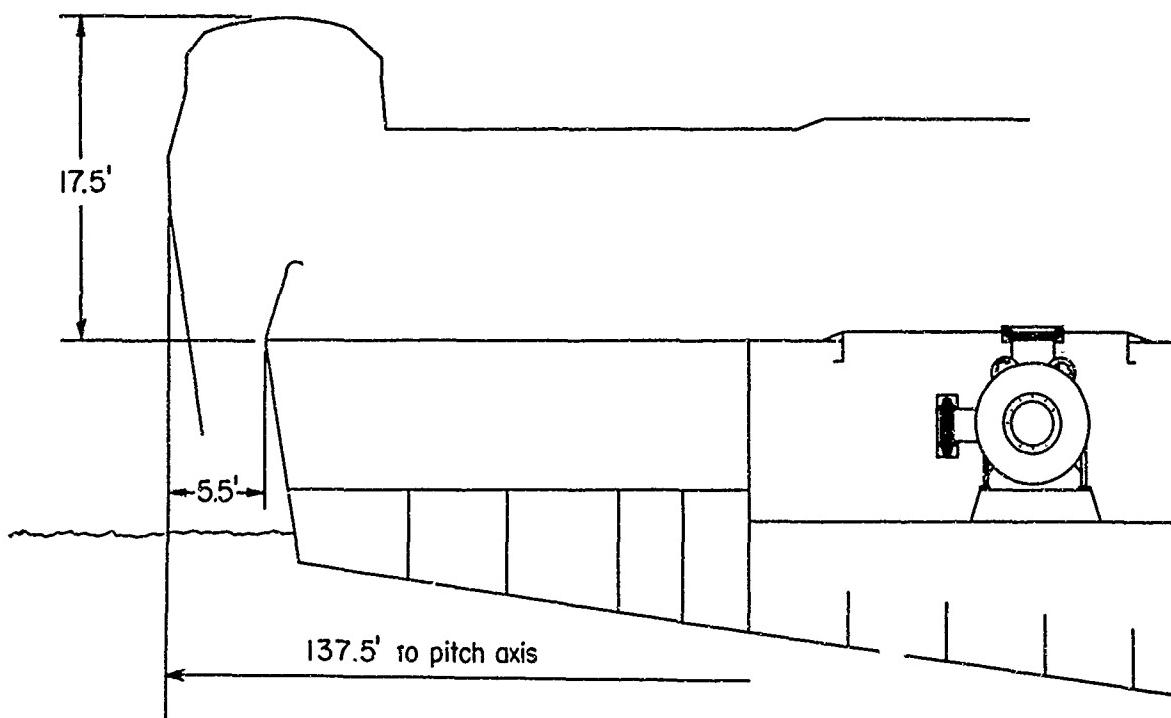


FIGURE 5. ATS STERN-DEPLOYMENT PATH

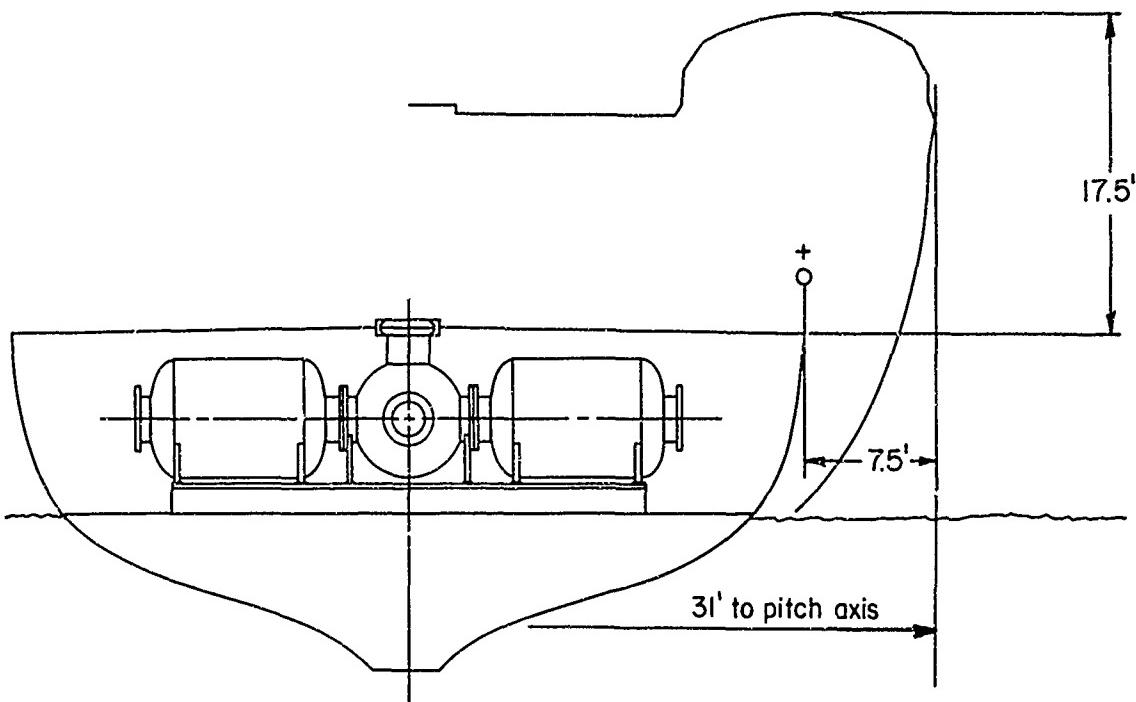


FIGURE 6. ATS SIDE-DEPLOYMENT PATH

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The relative motions between ship and sea determine the required lifting speed and the downward reach of the handling system. Lifting speed should be faster than wave rise for a period long enough to completely pull the PTC above the air-sea interface. Minimum downward reach must be great enough such that if the PTC is to be deployed and recovered from below the water, it will not reach the air-sea interface during the worst ship-sea movement. Understandably, actual required reach should be longer such that undesired water motions are minimized. However, how much longer would be determined during actual design of the handling system and is beyond the scope of this program.

The cable loads determine the required section moduli and power requirements of the handling-system components. These, in turn, yield size, weight, and CG information that is necessary for system comparison.

A computer program was written that calculates and plots ship motions and cable loads as a function of time. Ship motions plotted are relative ship-to-sea displacement and velocity. Cable loads plotted are forces on a cable just above the PTC when it is fixed relative to the ship either completely above or completely below the air-sea interface. Worst-case ship motions and cable loads occur at the outermost points on the handling path - the deployment/recovery points listed in the previous section. The computer program and plots are in Appendix D. The calculations were based on "Revised Ship Motions", Enclosure (1) to NAVSEC Ser. 152-6162, as shown in Appendix C. Important parameters quantified by the computer program are shown in Table 1.

TABLE 1. IMPORTANT PARAMETERS QUANTIFIED BY SHIP MOTION COMPUTER PROGRAM

	ATS-1 Side Deployment	ATS-1 Stern Deployment	ASR-13 Side Deployment	ASR-13 Stern Deployment
Maximum Relative Ship-to-Sea Displacement, ft	10.0	9.5	10.8	10.4
Maximum Displacement Frequency, radians/sec	1.25	1.08	1.28	1.26
Maximum Relative Ship-to-Sea Velocity, ft/sec	10.0	10.5	14.0	12.5
Maximum-Velocity Frequency, radians/sec	1.25	1.16	1.26	1.31
Average Cable Load, PTC Above Air-Sea Interface, lb	18,000	18,000	18,000	18,000
Maximum Alternating Cable Load, PTC Above Air-Sea Interface, lb	3,750	5,500	8,000	6,500
Maximum Frequency of Alternating Cable Load, PTC Above Air-Sea Interface, radians/sec	1.06	1.05	1.28	1.31
Average Cable Load, PTC Below Air-Sea Interface, lb	600	600	600	600
Maximum Alternating Cable Load, PTC Below Air-Sea Interface, lb	4,600	5,300	10,000	8,400
Maximum Frequency of Alternating Cable Load, PTC Below Air-Sea Interface, radians/sec	1.05	1.05	1.26	1.26

Available Deck Area and Layout. Early in the program, it was mutually agreed that a salvage capability was not necessary for ships equipped with the MKI DDS. Therefore, the following deck equipment which is used for salvage operation was considered removable:

ATS:	ASR:
Portable Bows	Four LWT Stern Anchors
Side Rollers	Side Rollers

Also considered removable were bulwark sections and the submarine rescue chamber shown on the ASR 13 drawings. Aft portions of the main deck for the ASR 13 and ATS I are shown, respectively, in Figures 7 and 8. Removable items are shaded, while nonremovable items such as capstans, and stern rollers are left in.

#### Feasible Handling Systems

This section includes verbal descriptions, characteristics, operation steps, and layout drawings of the following handling systems:

- A-frame, ASR/ARS Class Ships
- Articulated Telescoping Crane, ASR/ARS Class Ships
- Four-Tugger Winch-Boom System, ASR/ARS Class Ships
- A-Frame on Rails, ATS Class Ships
- Articulated Telescoping Crane, ATS Class Ships

System characteristics listed are:

- Weight - total weight of all major handling-system components excluding SPCC and SPCC winch
- Size - total envelope volume of all major handling system components excluding SPCC and SPCC winch
- Moment About Ships Keel - total moment about ships keel of all major handling system components except SPCC and SPCC winch
- Cost - estimated approximate cost of a delivered-handling system excluding installation.

Layout drawings of each system can be found in Appendix K.

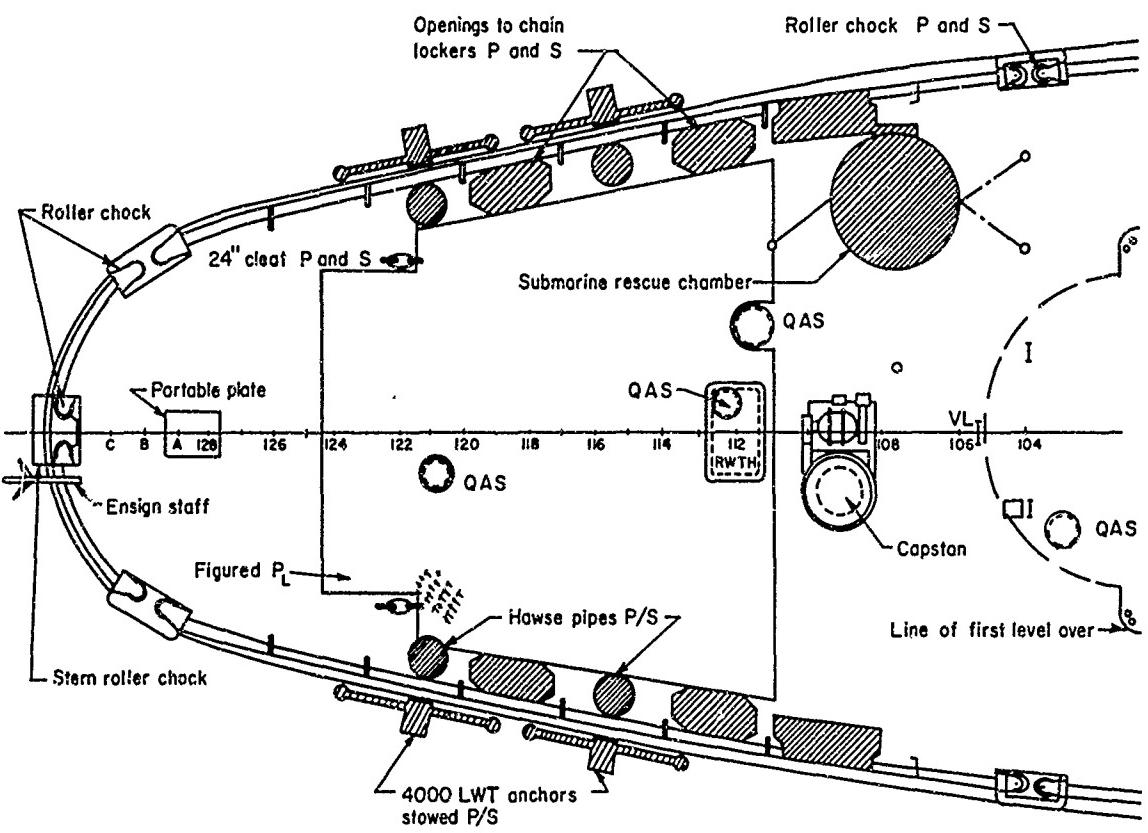


FIGURE 7. ASR 13 AFT-DECK LAYOUT

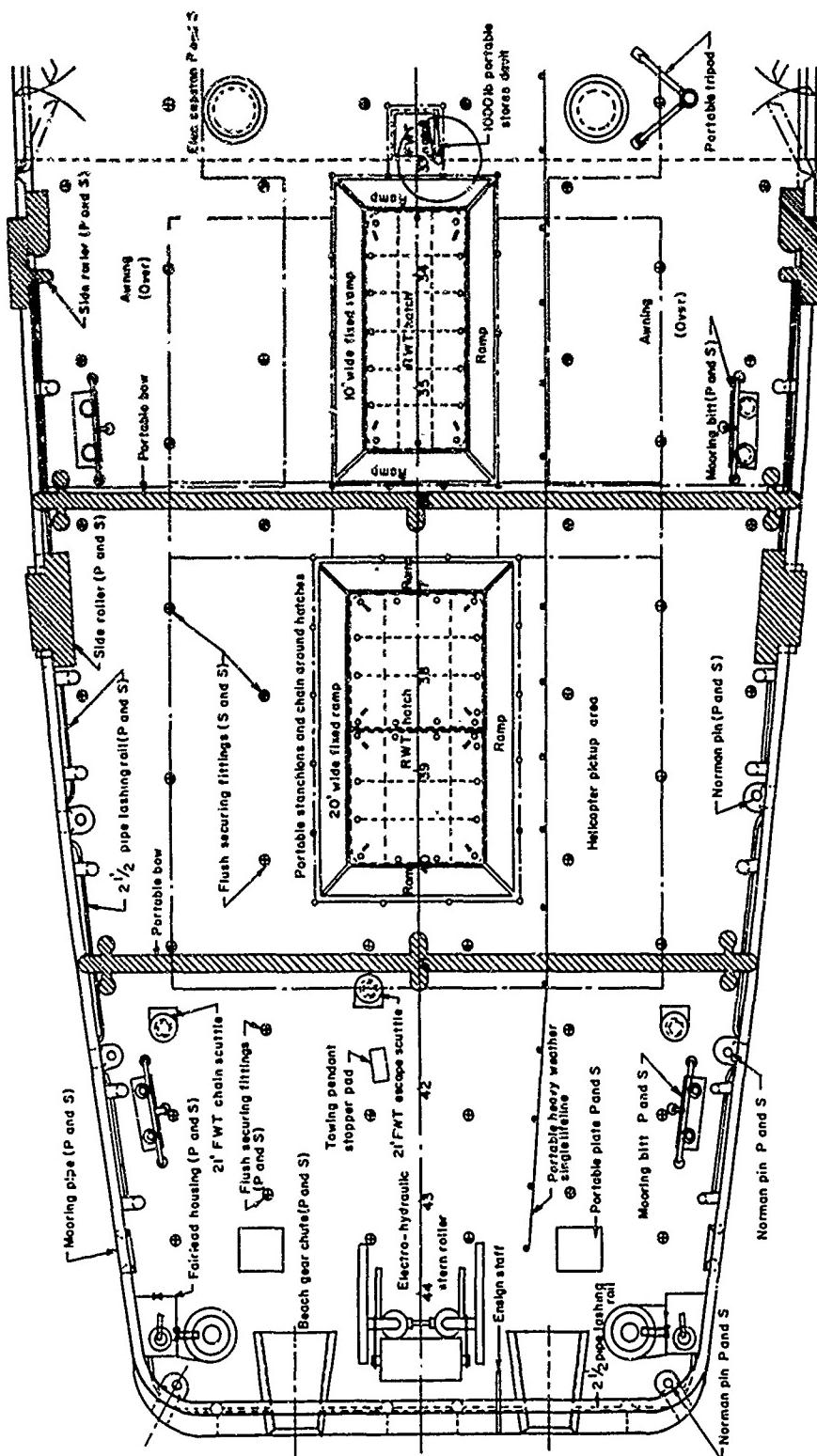


FIGURE 8. ATS 1 AFT-DECK LAYOUT

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### A-Frame, ASR/ARS Class Ships

In this system, shown in Figures 9, 10, and 11, the PTC is transferred between the EL and the deployment/recovery point by an A-frame hinged near the edge of the deck. Power is provided by two hydraulic cylinders and a constant-tension winch. The A-frame idea is not new; several are presently being successfully used to handle deep-dive submersibles. Vickers Ltd., Barrow Shipbuilding Works, has an aluminum A-frame fitted to the "Vickers Venturer" that has been used to recover a 12-ton body in Sea State 4/5.

Two problems are inherent to an A-frame handling system. First, an underwater deployment/recovery point 10 feet below the surface requires a long reach, and hence a large A-frame. Second, undesired ship motion during deployment and recovery cannot be fully compensated by the single degree of freedom available. Both problems were overcome by the addition of a hinged pendant at the apex of the frame. The pendant is positioned such that it rests against the A-frame and is fixed relative to the ship when the A-frame is topside. When the A-frame is lowered to the sea the pendant gravitates away from the A-frame yielding an adequate reach and an added degree of freedom.

The major problem in designing an A-frame for the ASR/ARS class ships is a shortage of available deck space. This problem was overcome by placing the A-frame hinges outboard such that the A-frame uses none of the available deck space and swings over some of the Deep Dive System components.

A-frame material is 6061-T6 aluminum, which helps keep handling system weight to 36,600 lb. System layout is such that the ship's towing winch could possibly be used instead of the constant tension winch. This would reduce system weight to 12,600 lb.

#### System Characteristics

Weight	36,600 lb
Size	1330 cu ft
Moment about ship's keel	1,055,500 ft-lb
Cost	\$89,100

#### Operation Steps

##### Deployment

- (1) SPCC put over pendant saddle
- (2) Auxilliary cable connected to PTC
- (3) PTC pulled against automatic latch
- (4) A-frame powered over-center by hydraulic cylinders
- (5) A-frame lowered into water by constant-tension winch
- (6) Automatic latch released
- (7) PTC lowered 20 feet
- (8) Diver pulls SPCC off pendant saddle
- (9) Diver unhooks auxilliary cable
- (10) PTC lowered to work site by SPCC
- (11) A-frame pulled over-center by constant-tension winch
- (12) A-frame powered down by hydraulic cylinders

##### Recovery

- (1) A-frame powered over-center by hydraulic cylinders
- (2) A-frame lowered by constant-tension winch
- (3) Auxilliary cable lowered to PTC
- (4) Diver hooks up auxilliary cable
- (5) PTC pulled against automatic latch
- (6) Diver leads SPCC over pendant saddle
- (7) A-frame with PTC pulled out of sea and over-center by constant-tension winch
- (8) A-frame with PTC lowered by hydraulic cylinders
- (9) Automatic latch released
- (10) PTC lowered onto EL by auxilliary cable
- (11) Auxilliary cable disconnected
- (12) SPCC taken off pendant saddle

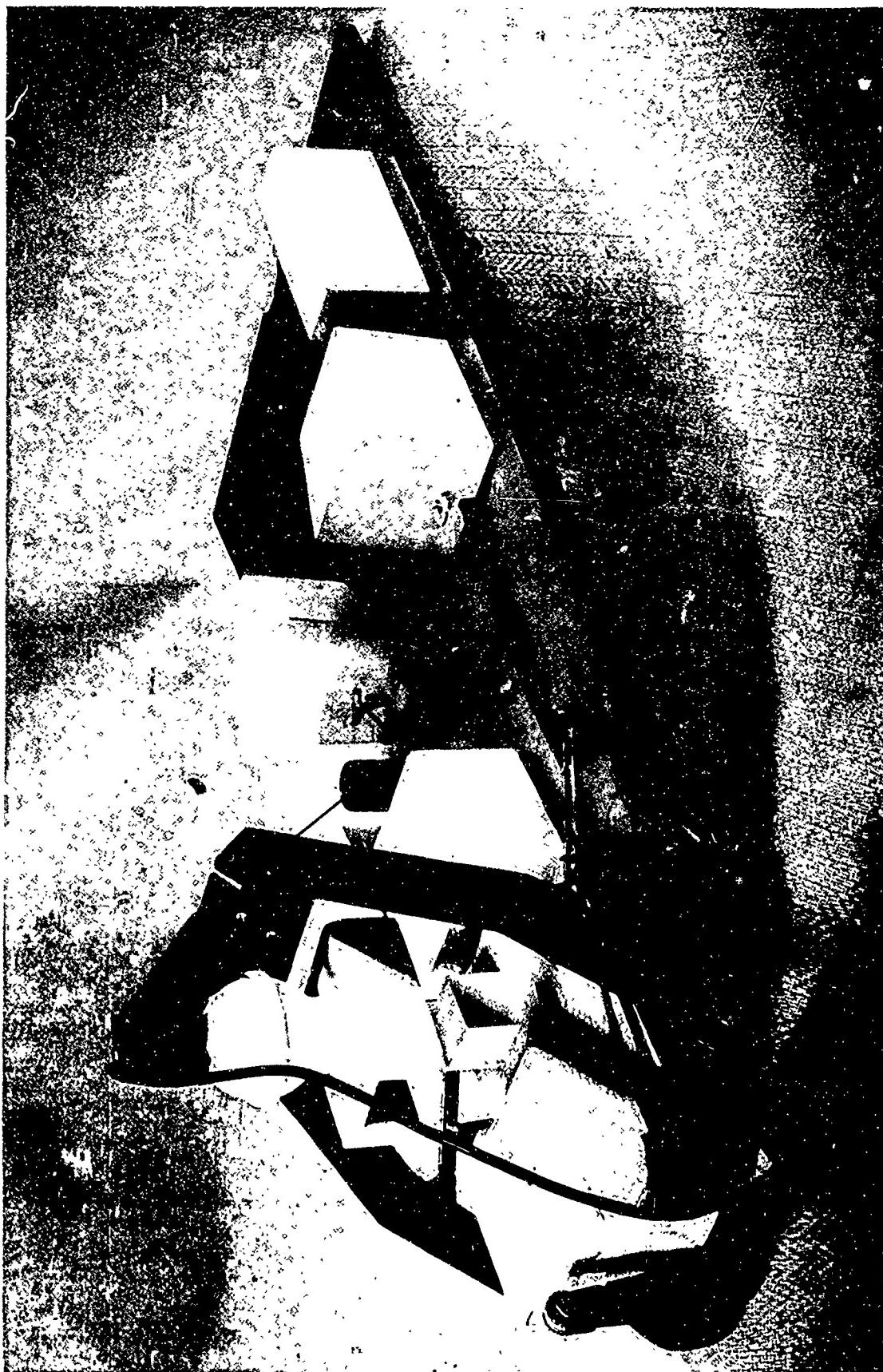


FIGURE 9. A-FRAME, ASR/ARS CLASS SHIPS, REST POSITION

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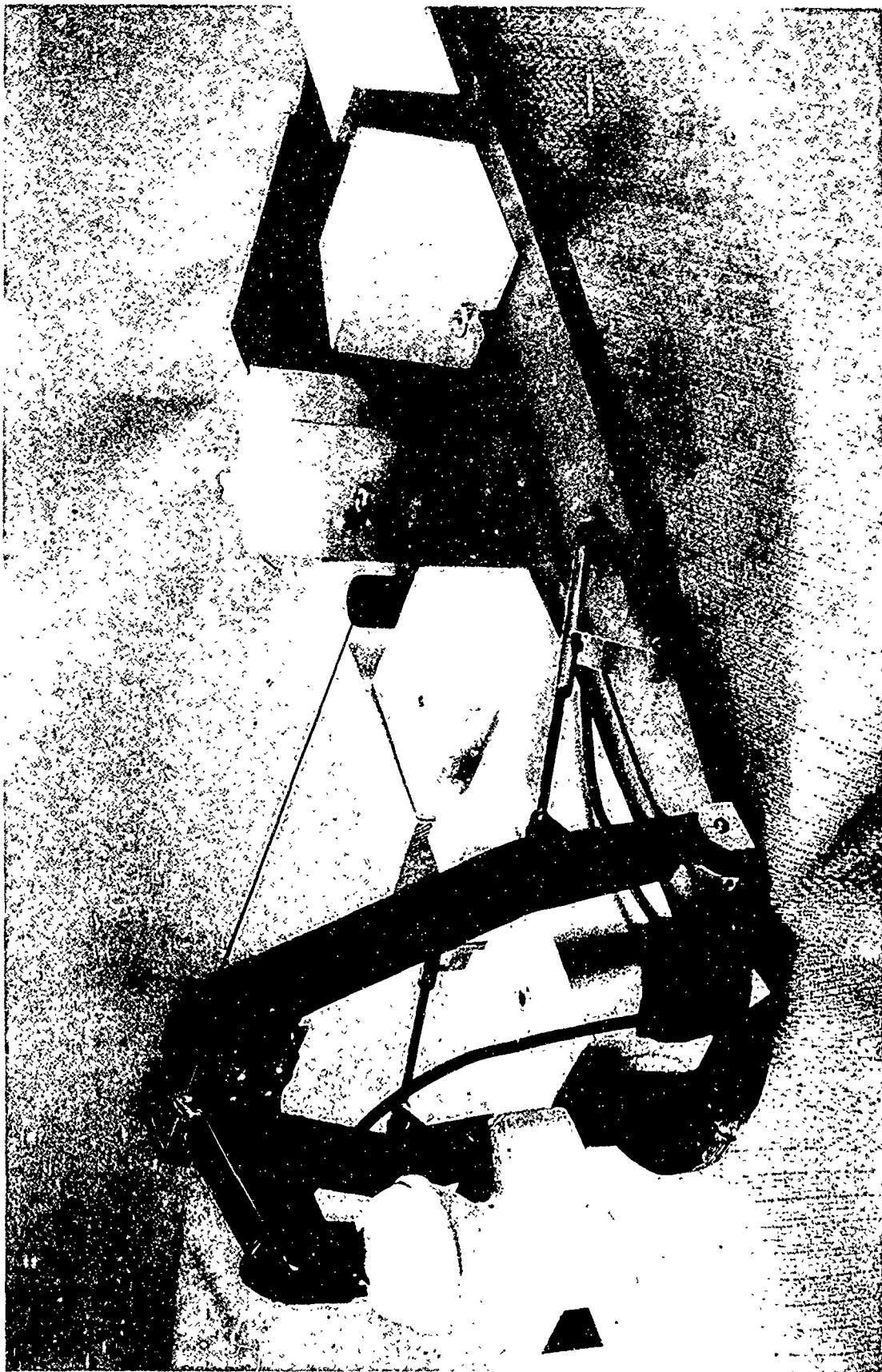


FIGURE 10. A-FRAME, ASR/ARS CLASS SHIPS, INTERMEDIATE POSITION

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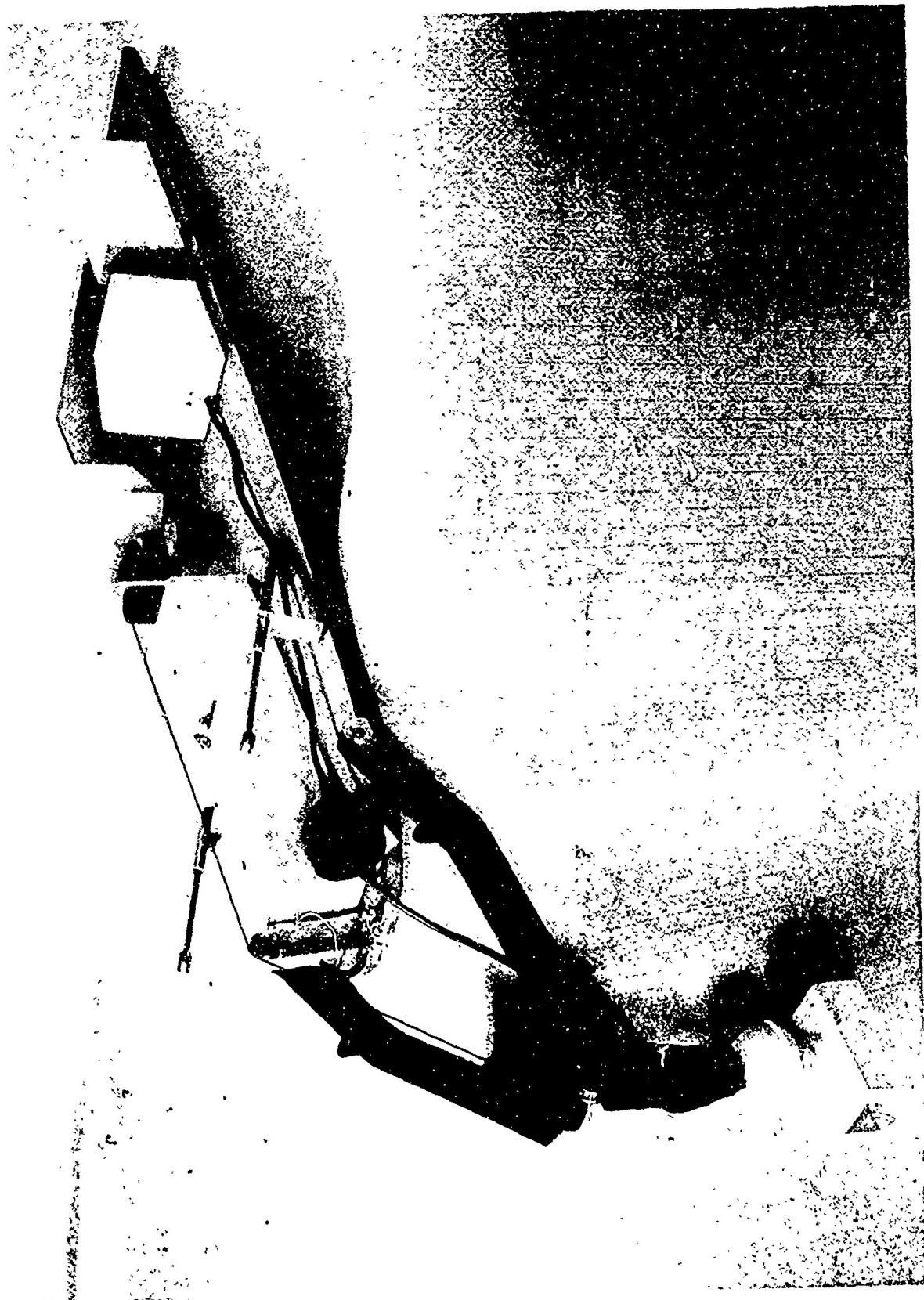


FIGURE 11. A-FRAME, ASR/ARS CLASS SHIPS, DEPLOYMENT POSITION

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### Articulating Telescoping Crane, ASR/ARS Class Ships

In this system, shown in Figures 12, 13, and 14, the PTC is transferred between EL and deployment/recovery point by an articulated crane. Power is self-contained in the unit which is mounted on a rotation bearing welded or bolted to the deck. The articulating crane is a popular concept and many are being used in successful handling of submersibles. However, none presently being used allow a pickup/deployment point 10 feet below the surface. Also, only a few have automatic ship-motion compensation. Both problems were overcome by the addition of a dual mode (power/damp) hydraulic cylinder as the outermost member of the crane arm.

Extension of the added cylinder yields a deployment/recovery point 10 feet below the surface, and the damping mode of the cylinder provides ship-motion compensation during pickup. After pickup, a gradual increase in damping, until the PTC is fixed relative to the crane, is provided by adjustable orifices.

The crane body and rotation bearing are commercially available. An Insley H-2000 Hydraulic Backhoe was used in the engineering analysis. The dual-mode hydraulic cylinder and auxiliary cable winch would be the major additions to the existing unit.

#### System Characteristics

Weight	56,800 lb
Size	12' 1 cu ft
Moment about ships keel	1,590,400 ft-lb
Cost	\$115,000

#### Operation Steps

##### Deployment

- (1) Crane moved from stowage position to EL
- (2) SPCC put over latch saddle
- (3) Auxilliary cable connected to PTC
- (4) PTC pulled against automatic latch
- (5) Crane moves PTC to underwater-deployment position
- (6) Automatic latch released
- (7) PTC lowered 20 feet
- (8) Diver pulls SPCC off latch saddle
- (9) Diver unhooks auxilliary cable
- (10) PTC lowered to work site by SPCC
- (11) Crane moved to rest position

##### Recovery

- (1) Crane moved from rest position to underwater-recovery point
- (2) Auxilliary cable lowered to PTC
- (3) Diver hooks up auxilliary cable
- (4) PTC pulled snug to automatic latch (cylinder in damp mode)
- (5) Diver leads SPCC over latch saddle
- (6) Crane moves PTC to EL
- (7) Automatic latch released
- (8) Auxilliary cable disconnected
- (9) SPCC taken off latch saddle
- (10) Crane moved to rest position

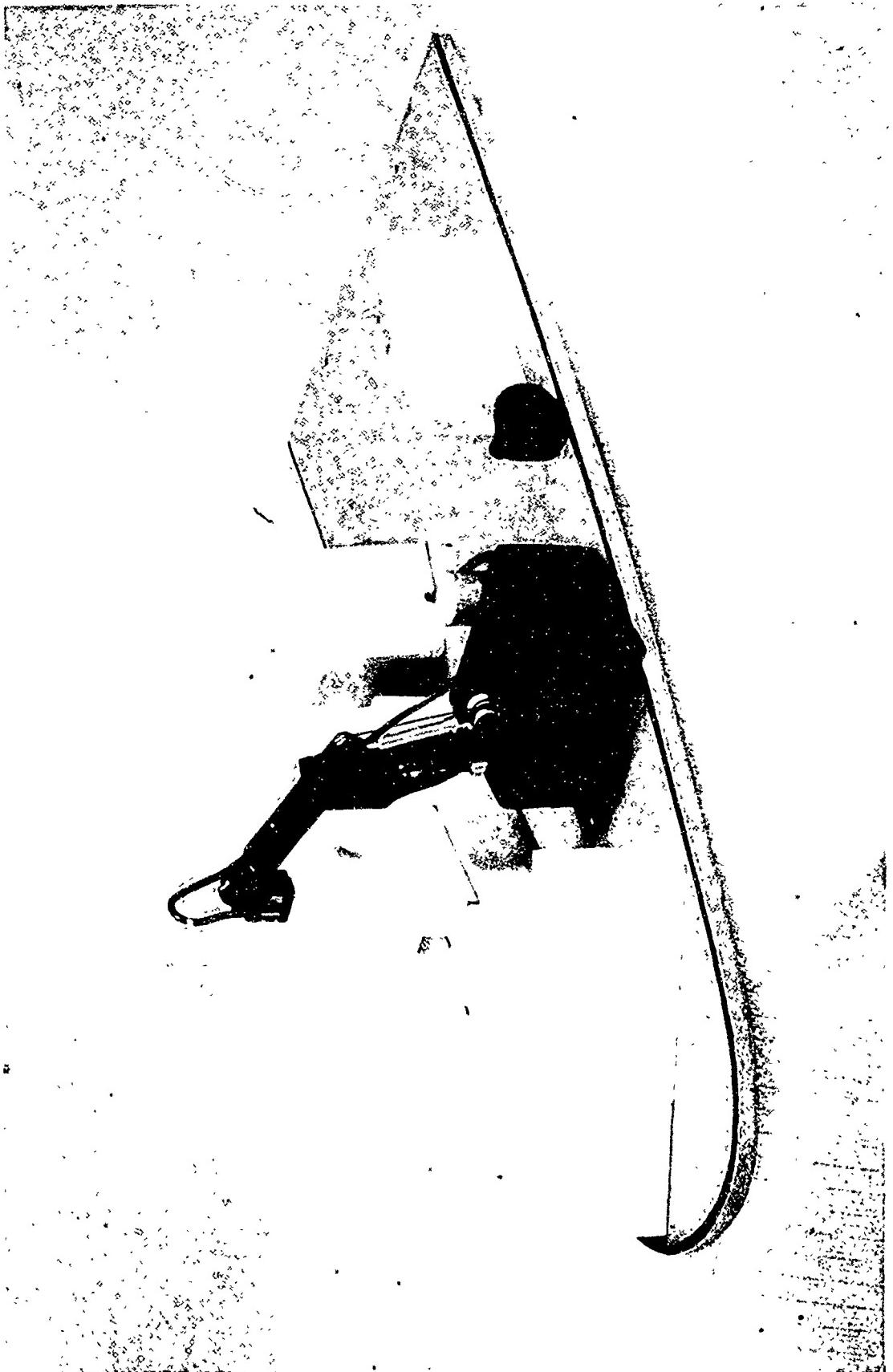
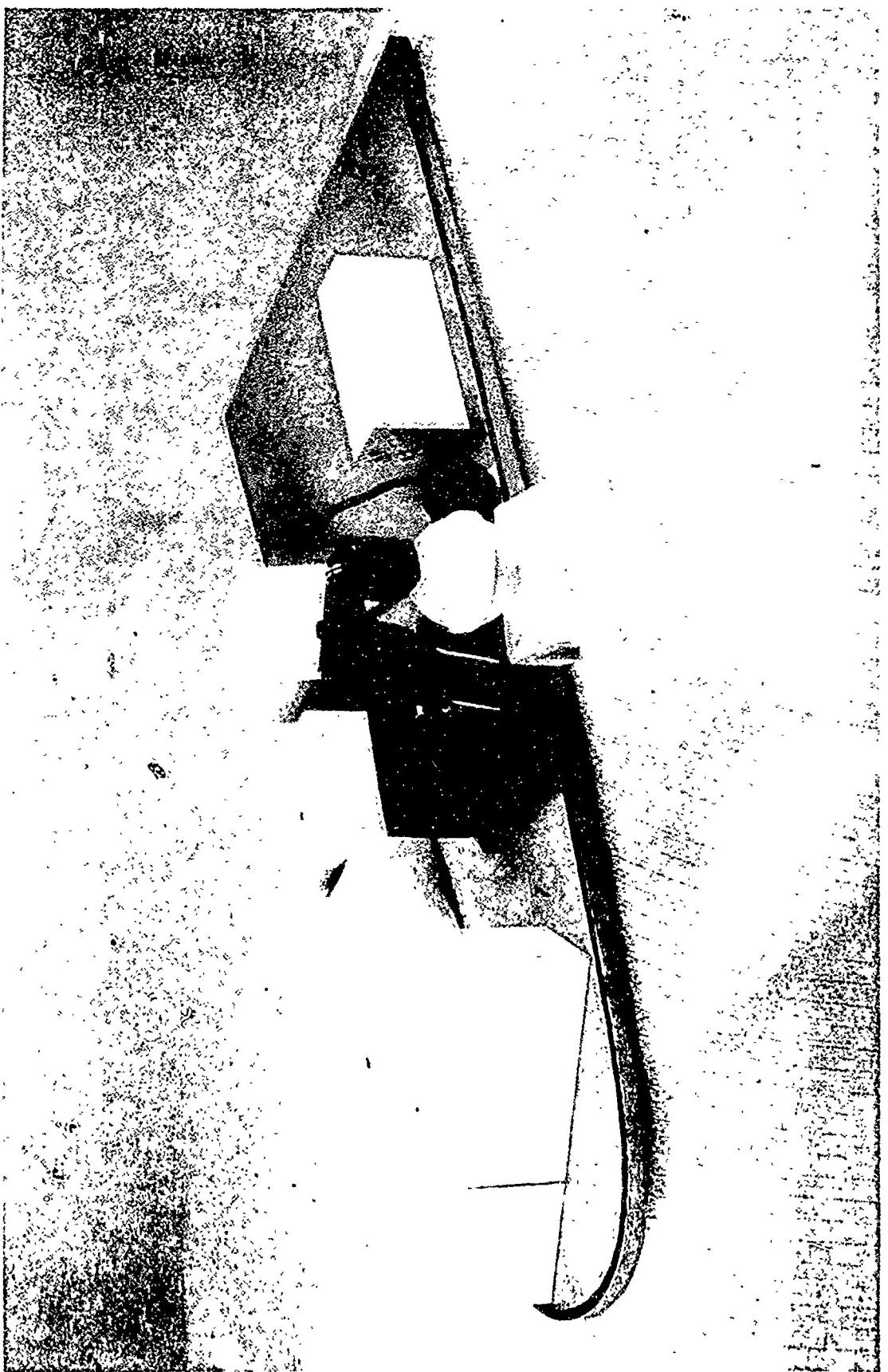


FIGURE 12. ARTICULATED TELESCOPING CRANE, ASR/ARS CLASS SHIPS, REST POSITION

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FIGURE 13. ARTICULATED TELESCOPING CRANE, ASR/ARS CLASS SHIPS, INTERMEDIATE POSITION

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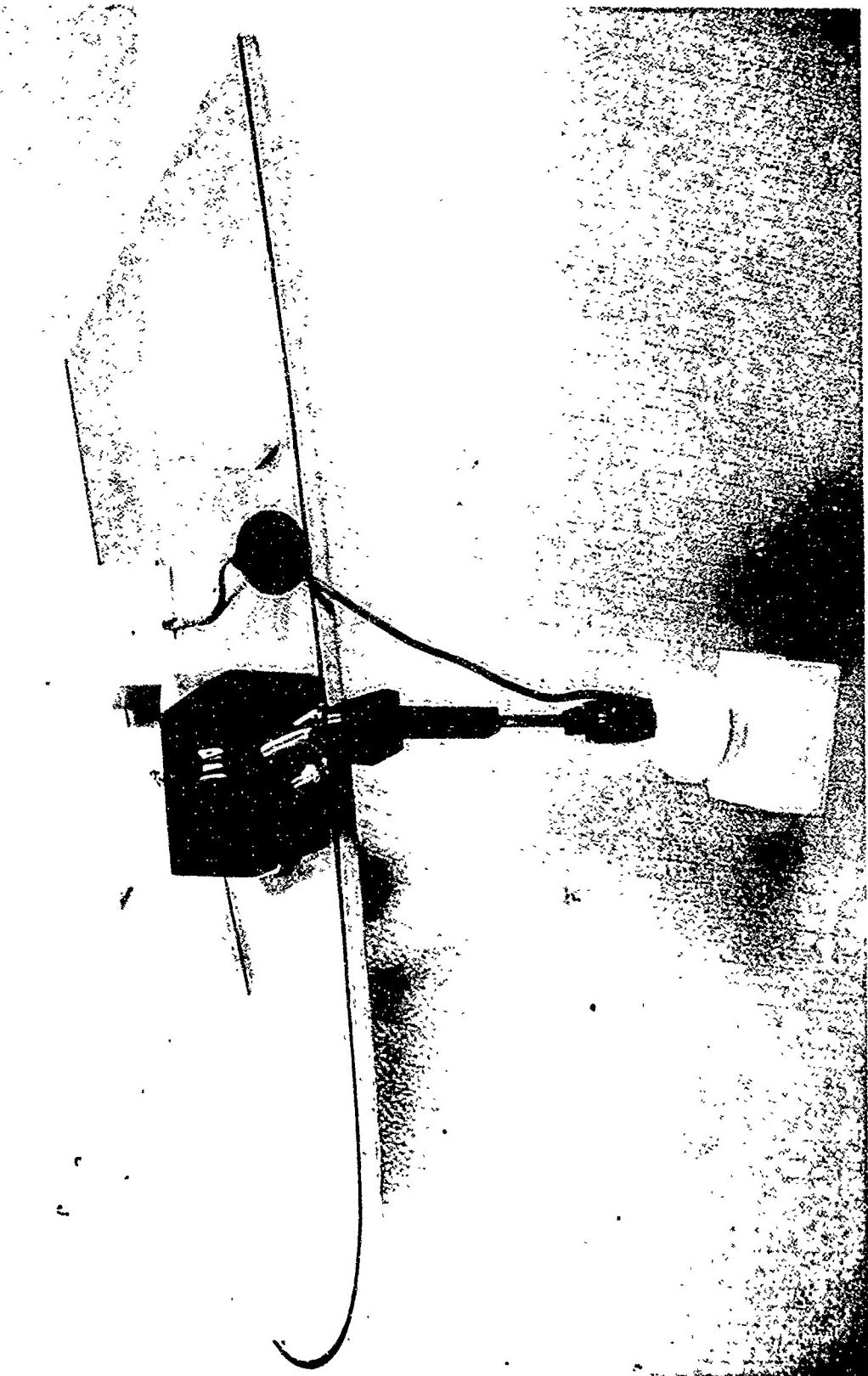


FIGURE 14. ARTICULATED TELESCOPING CRANE, ASR/ARS CLASS SHIPS, DEPLOYMENT POSITION

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### A-Frame on Rails, ATS Class Ships

The major problem in designing an A-frame for the ATS class ships was the beam magnitude. A single arm pivoting between the EL and the deployment/recovery point would be far too large. The solution, shown in Figures 15, 16, 17, and 18, was to mount the A-frame on a carriage with wheels and to use rails to guide the carriage between EL and the edge of the deck. Carriage power is provided by a linear actuator such as a ballscrew or a hydraulic cylinder.

This A-frame incorporates a pendant similar to the device used on the ASR/ARS A-frame. It is positioned such that it rests against the A-frame and is fixed relative to the ship when the A-frame is topside. When the A-frame is lowered to the sea the pendant gravitates away from the A-frame yielding an adequate reach and an added degree of freedom.

A-frame material is 6061-T6 aluminum; however, system weight is 55,200 lb. The carriage, rails, and wheels represent 21,000 lb. Thus 38 percent of the system weight is equipment needed to overcome beam magnitude.

#### System Characteristics

Weight	55,200 lb
Size	2310 cu ft
Moment about ships keel	1,633,100 ft-lb
Cost	\$107,000

#### Operation Steps

##### Deployment

- (1) A-frame moved from stowage position to EL
- (2) SPCC put over pendant saddle
- (3) Auxilliary cable connected to PTC
- (4) PTC pulled against automatic latch
- (5) A-frame slid to deployment position
- (6) A-frame powered over-center by hydraulic cylinders
- (7) A-frame lowered into water by constant-tension winch
- (8) Automatic latch released
- (9) PTC lowered 20 feet
- (10) Diver pulls SPCC off pendant saddle
- (11) Diver unhooks auxilliary cable
- (12) PTC lowered to work site by SPCC
- (13) A-frame pulled over-center by constant-tension winch
- (14) A-frame powered down by hydraulic cylinders
- (15) A-frame moved to rest position

##### Recovery

- (1) A-frame slid from rest position to recovery location
- (2) A-frame powered over-center by hydraulic cylinders
- (3) A-frame lowered by constant-tension winch
- (4) Auxilliary cable lowered to PTC
- (5) Diver hooks up auxilliary cable
- (6) PTC pulled against automatic latch
- (7) Diver leads SPCC over pendant saddle
- (8) A-frame with PTC pulled out of sea and over-center by constant-tension winch
- (9) A-frame with PTC lowered by hydraulic cylinders
- (10) A-frame slid over to EL
- (11) Automatic latch released
- (12) PTC lowered onto EL by auxilliary cable
- (13) Auxilliary cable disconnected
- (14) SPCC taken off pendant saddle
- (15) A-frame slid to stowage position

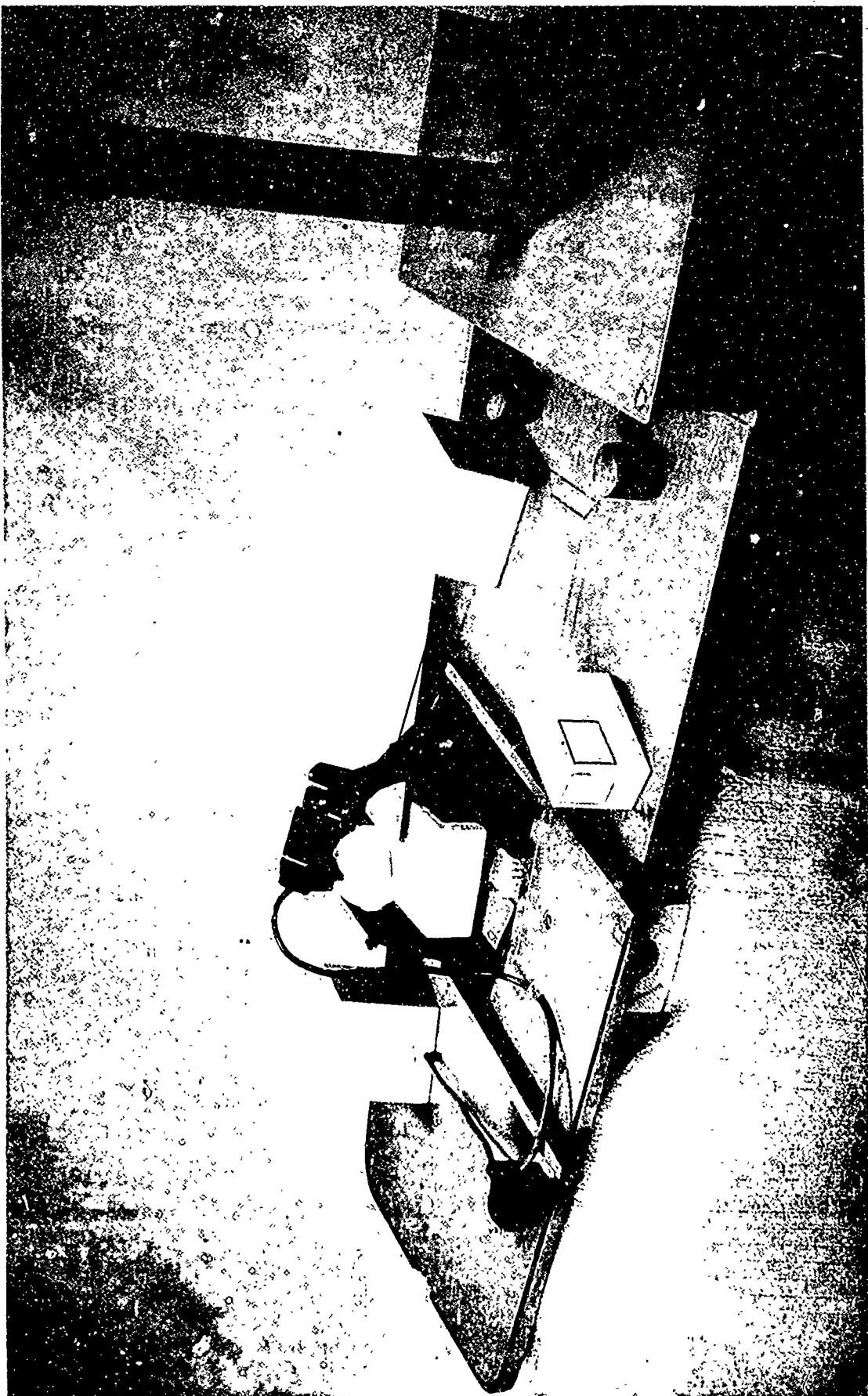
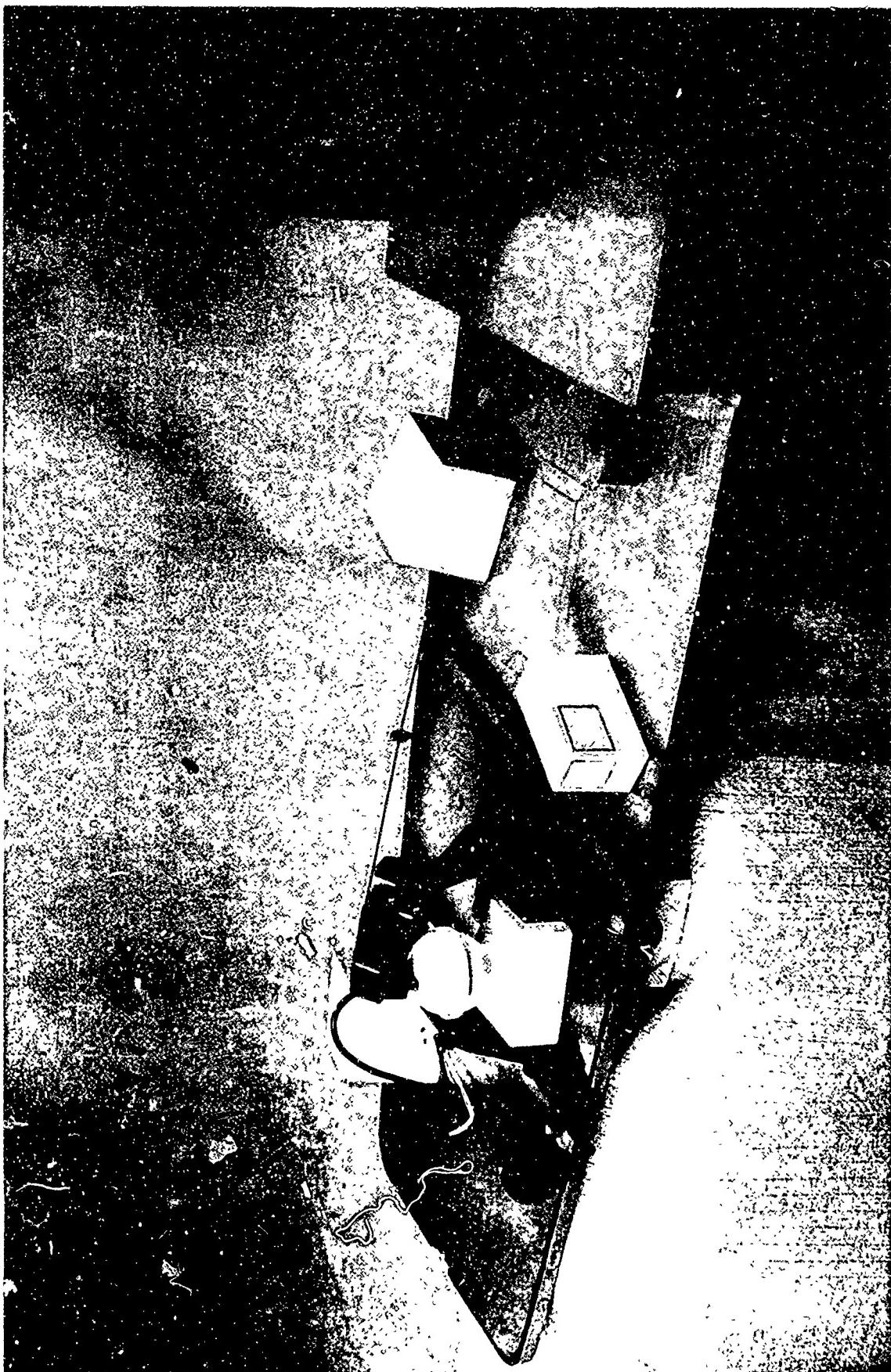


FIGURE 15. A-FRAME ON RAILS, ATS CLASS SHIPS, REST POSITION

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FIGURE 16. A-FRAME ON RAILS, ATS CLASS SHIPS, INTERMEDIATE POSITION A.

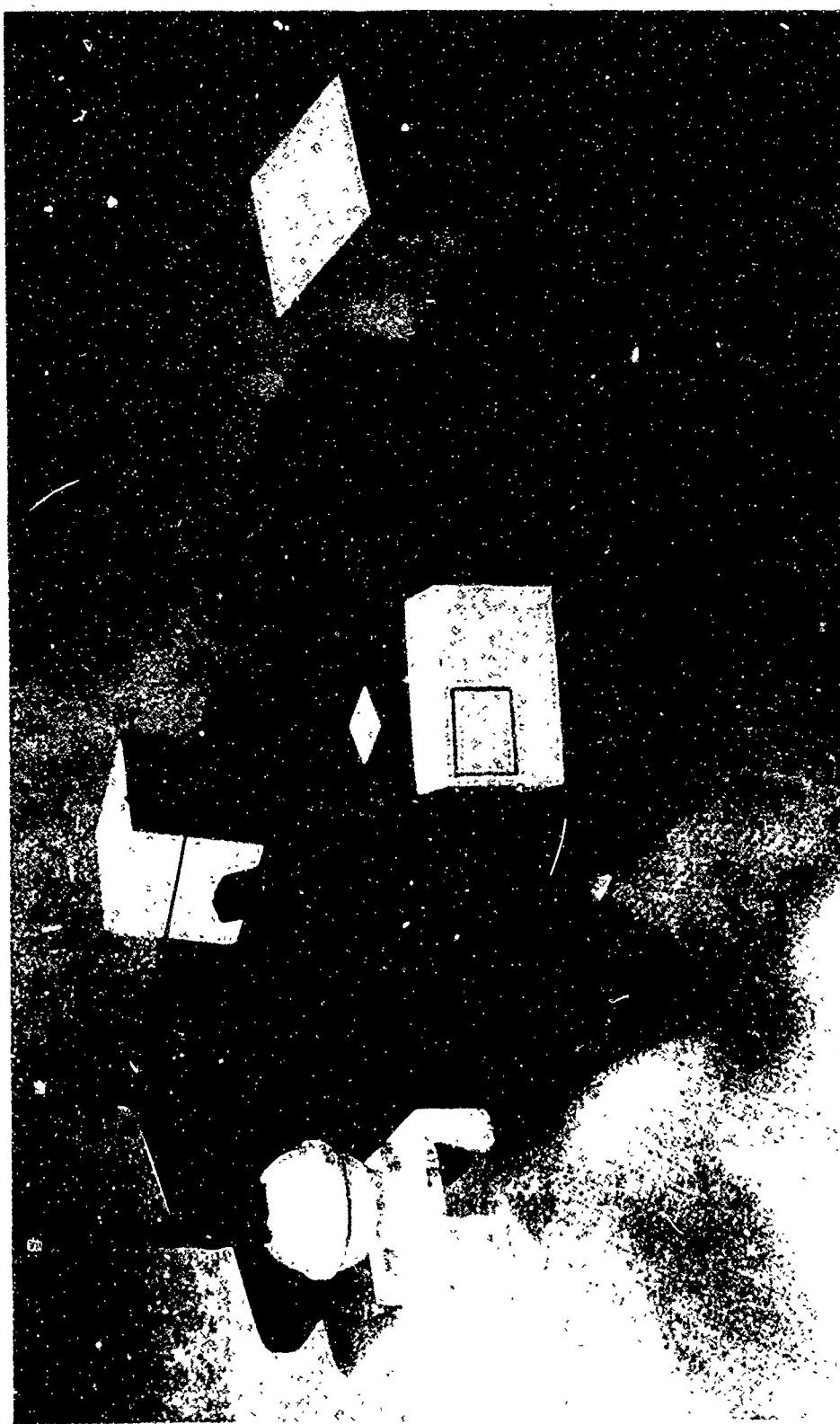
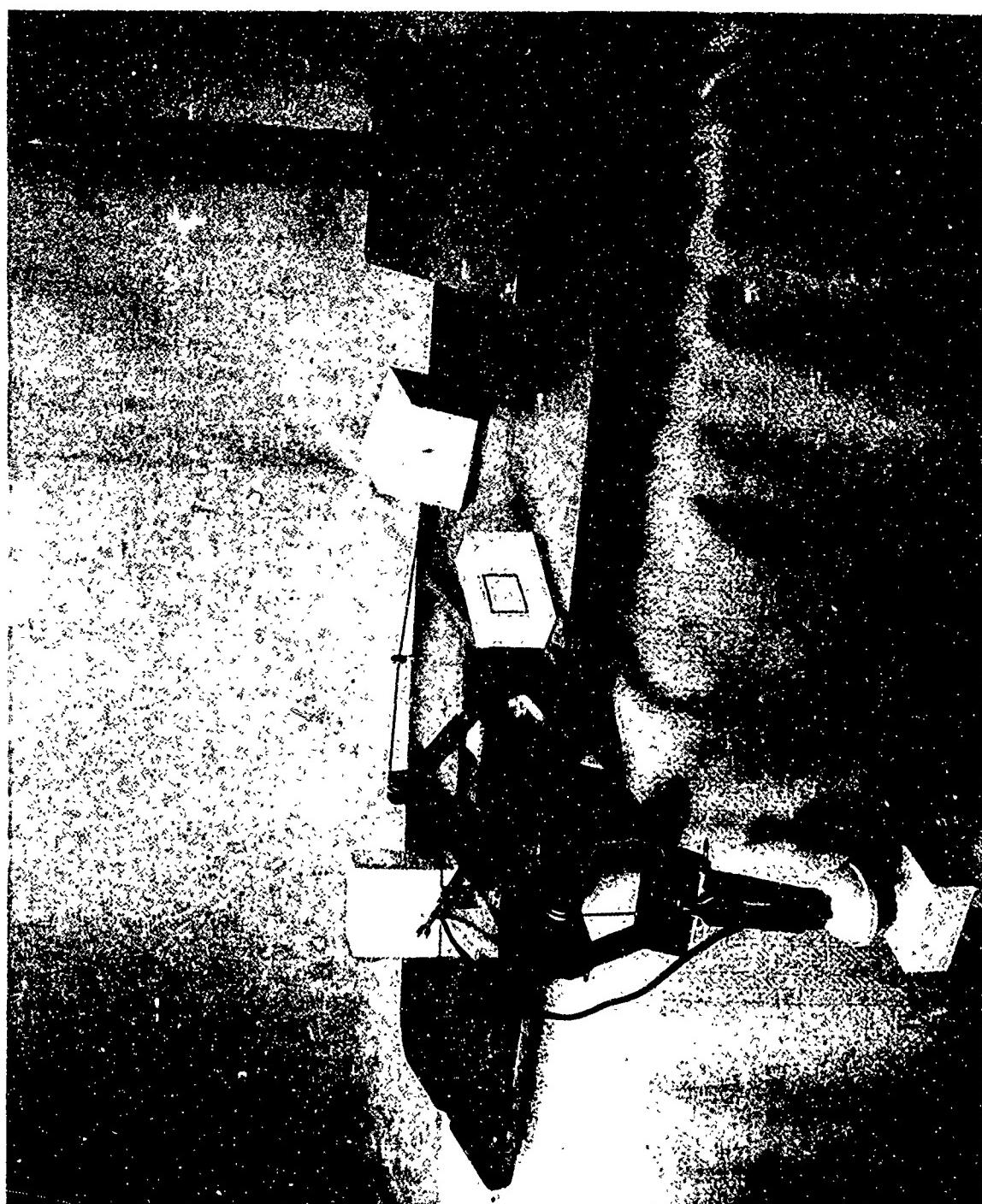


FIGURE 17. A-FRAME ON RAILS, ATS CLASS SHIPS, INTERMEDIATE POSITION B



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FIGURE 18. A-FRAME ON RAILS, ATS CLASS SHIPS, DEPLOYMENT POSITION

### Articulating Telescoping Crane, ATS Class Ships

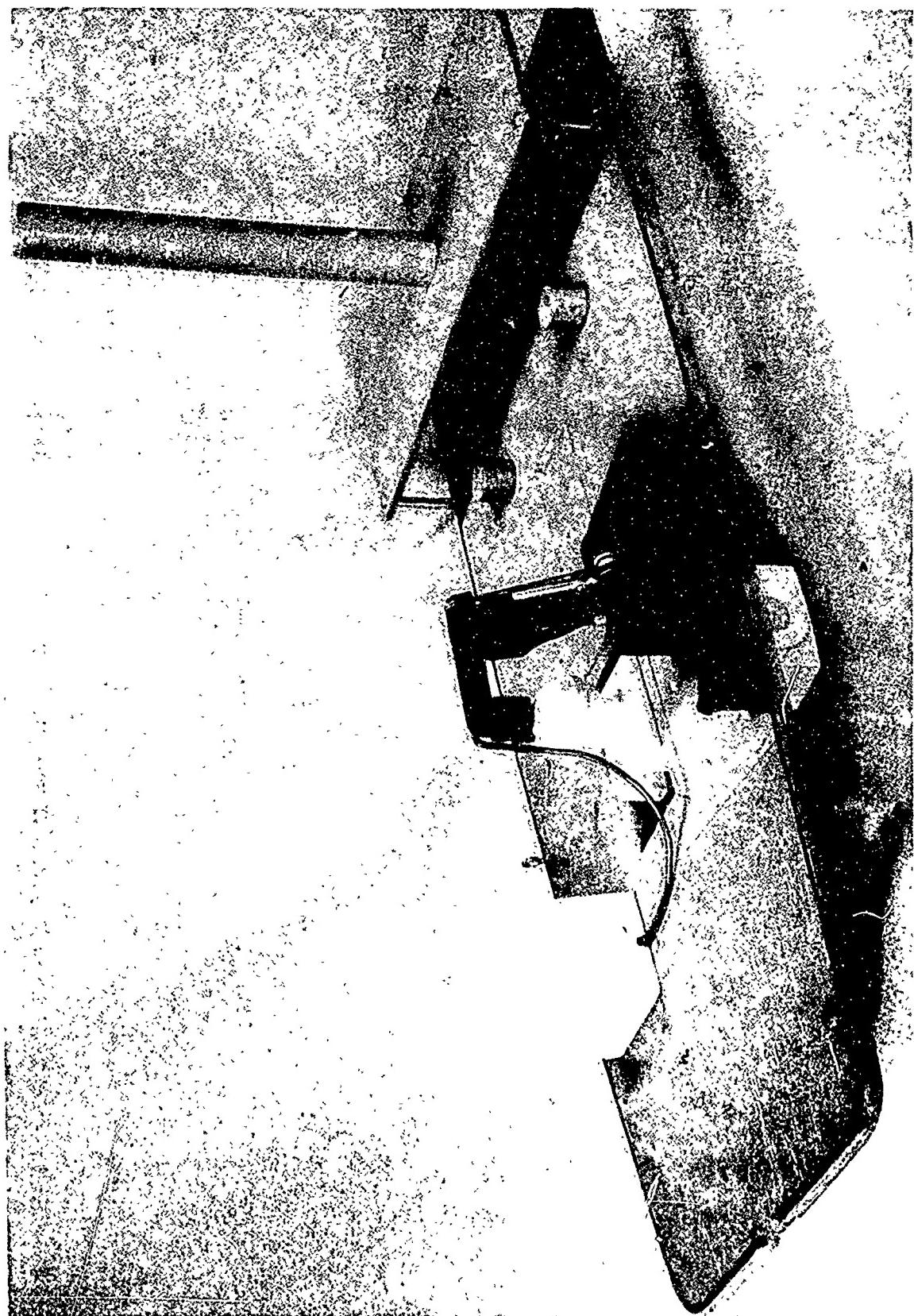
During engineering analysis of this system, shown in Figures 19, 20, and 21, and the articulating telescoping crane for ASR/ARS class ships it was found that an indentical handling system of this type could be used on both ships. Therefore, description of this system is the same as the aforementioned.

#### System Characteristics

Weight	56,800 lb
Size	1210 cu ft
Moment about ships keel	1,687,000 ft-lb
Cost	\$115,000

#### Operating Steps

- | <u>Deployment</u>                                     | <u>Recovery</u>   |
|---|---|
| (1) Crane moved from stowage position to EL           | (1) Crane moved from rest position to underwater-recovery point |
| (2) SPCC put over latch saddle                        | (2) Auxilliary cable lowered to PTC                             |
| (3) Auxilliary cable connected to PTC                 | (3) Diver hooks up auxilliary cable                             |
| (4) PTC pulled against automatic latch                | (4) PTC pulled snug to automatic latch (cylinder in damp mode)  |
| (5) Crane moves PTC to underwater-deployment position | (5) Diver leads SPCC over latch saddle                          |
| (6) Automatic latch released                          | (6) Crane moves PTC to EL                                       |
| (7) PTC lowered 20 feet                               | (7) Automatic latch released                                    |
| (8) Diver pulls SPCC off latch saddle                 | (8) Auxilliary cable disconnected                               |
| (9) Diver unhooks auxilliary cable                    | (9) SPCC taken off latch saddle                                 |
| (10) PTC lowered to work site by SPCC                 | (10) Crane moved to rest position                               |
| (11) Crane moved to rest position                     |   |



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FIGURE 19. ARTICULATED TELESCOPING CRANE, ATS CLASS SHIPS, REST POSITION

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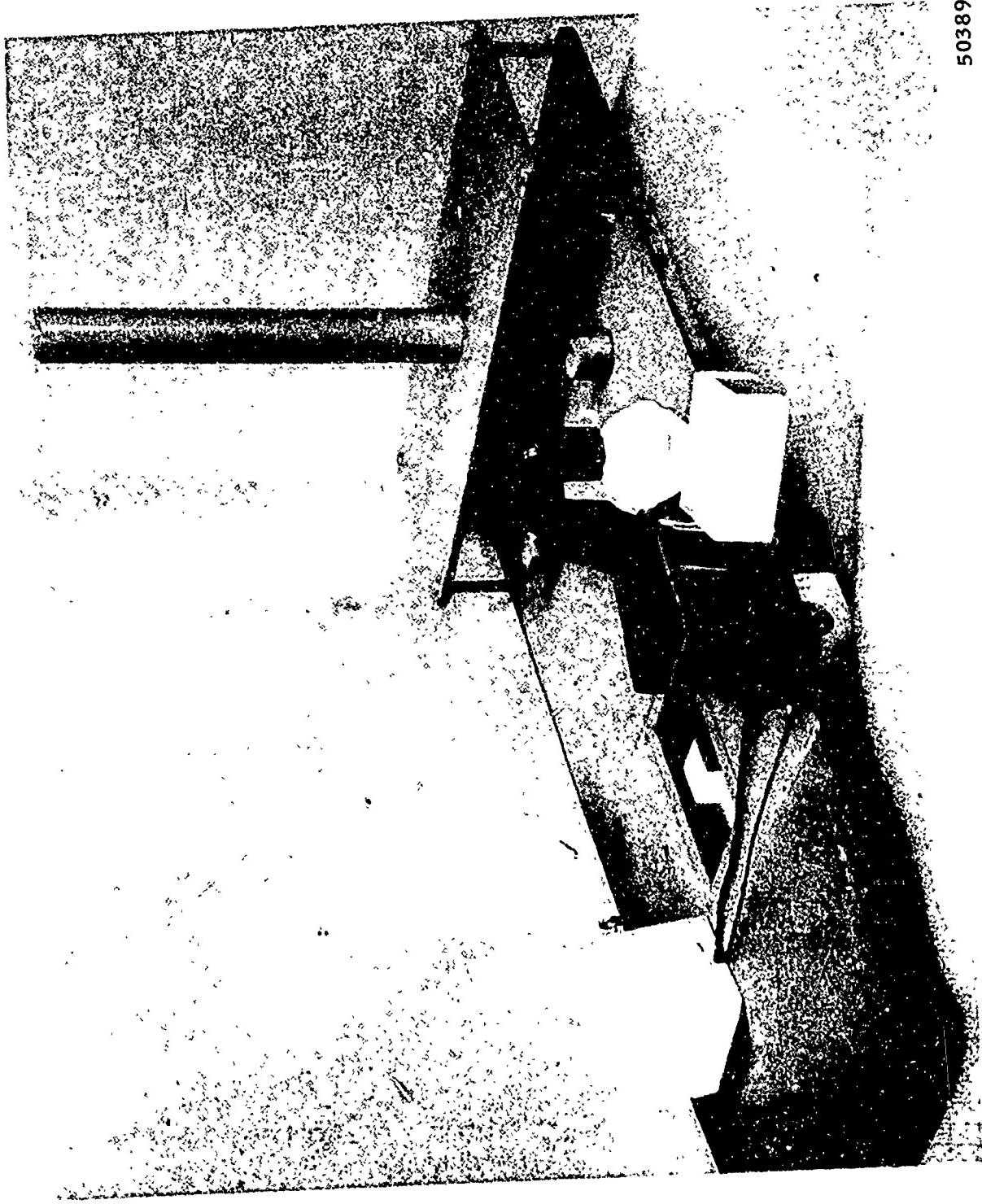
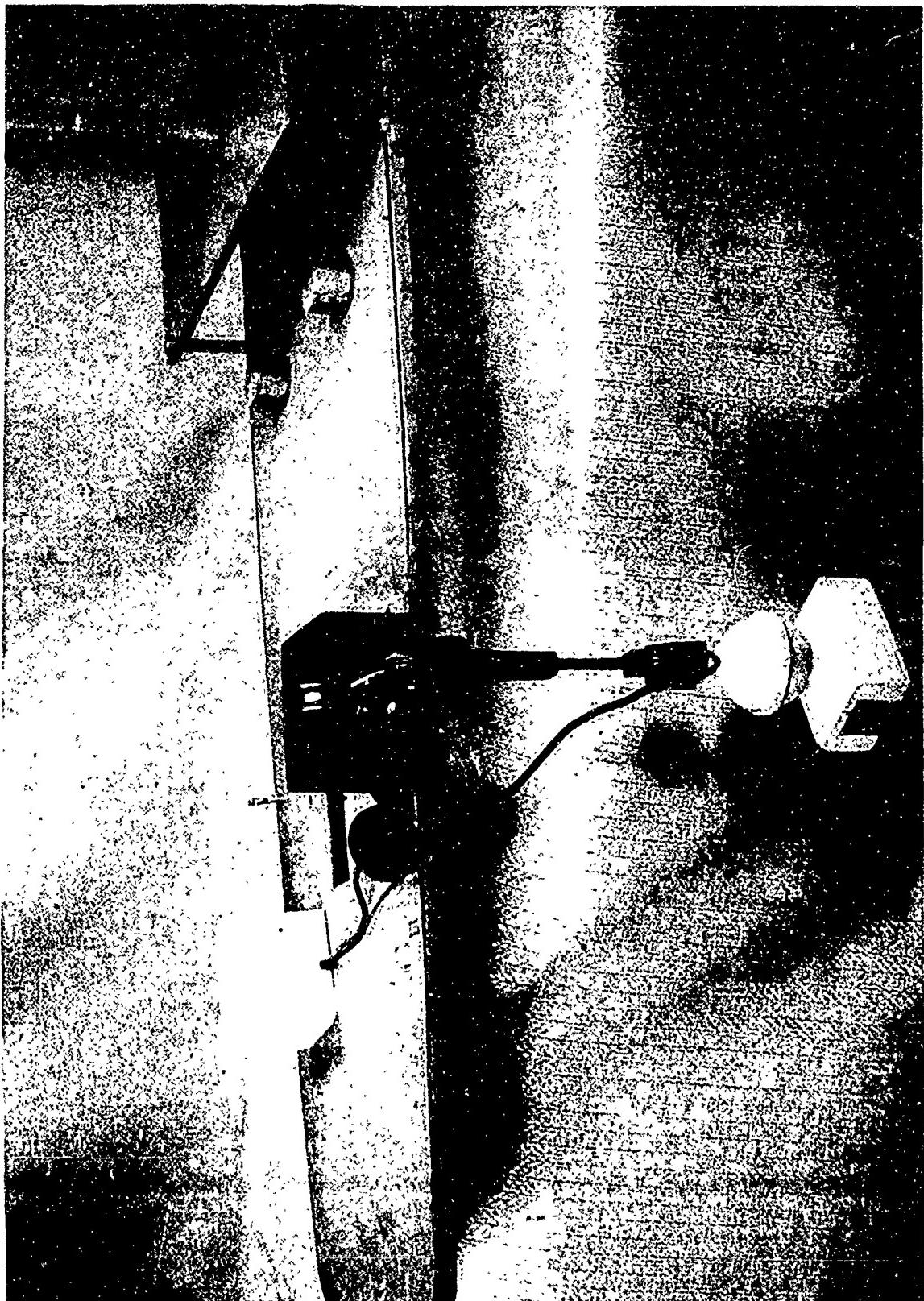


FIGURE 20. ARTICULATED TELESCOPING CRANE, ATS CLASS SHIPS, INTERMEDIATE POSITION

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FIGURE 21 ARTICULATED TELESCOPING CRANE, ATS CLASS SHIPS, DEPLOYMENT POSITION

### Four-Tugger Winch-Boom System ASR/ARS Class Ships

This handling system, shown in Figures 22, 23, and 24, is presently used aboard the USNS Gear (ARS 38). The ship's main boom is used in a conventional manner to support the weight of the PTC while it is being moved about. Four outrigger booms are used to fairlead steadyng lines from the tugger winches to the PTC. When setting the PTC on the EL, rotation is provided by two men with block and tackle.

This system was not one of the feasible concepts selected for analysis as the system is inoperable in a Sea State 3. The portside tugger booms are positioned such that the snubber lines must be disconnected when the PTC is overboard and below the bulwarks, a point where it subjected to extreme dynamic loads as it is continually immersed and uncovered by wave action. Also, it is reported that in heavy seas the forces caused by PTC dynamics are sufficient to strip cable off the tugger winches. However, at the suggestion of the Navy, this handling system was analyzed to serve as a reference in evaluating the other approaches.

#### System Characteristics

Weight	11,720 lb
Size	371 cu ft
Moment about ships keel	373,900 ft-lb
Cost	\$35,000

#### Operating Steps

- | <u>Deployment</u>   | <u>Recovery</u>  |
|---|--|
| (1-4) Four tugger booms lowered from vertical stowage position to deployment position | (1) Ships hook connected to PTC                        |
| (5-8) Four tugger lines connected to PTC  | (2) SPCC guided over saddle on ships boom              |
| (9) SPCC guided over saddle on ships boom   | (3-6) Four tugger lines connected to PTC               |
| (10) Ships hook attached to PTC   | (7) PTC moved from sea position above EL               |
| (11) PTC moved from EL to underwater-deployment point                                 | (8-9) Two block and tackles connected to PTC           |
| (12-15) Four tugger lines disconnected  | (10) PTC lowered onto EL                               |
| (16) SPCC taken off boom saddle and put on over the side sheave                       | (11) SPCC taken off saddle on ships boom               |
| (17) Ships hook disconnected from PTC   | (12-15) Four tugger lines disconnected                 |
| (18) PTC lowered on SPCC  | (16) Ships hook disconnected                           |
|   | (17-20) Four tugger booms returned to stowage position |

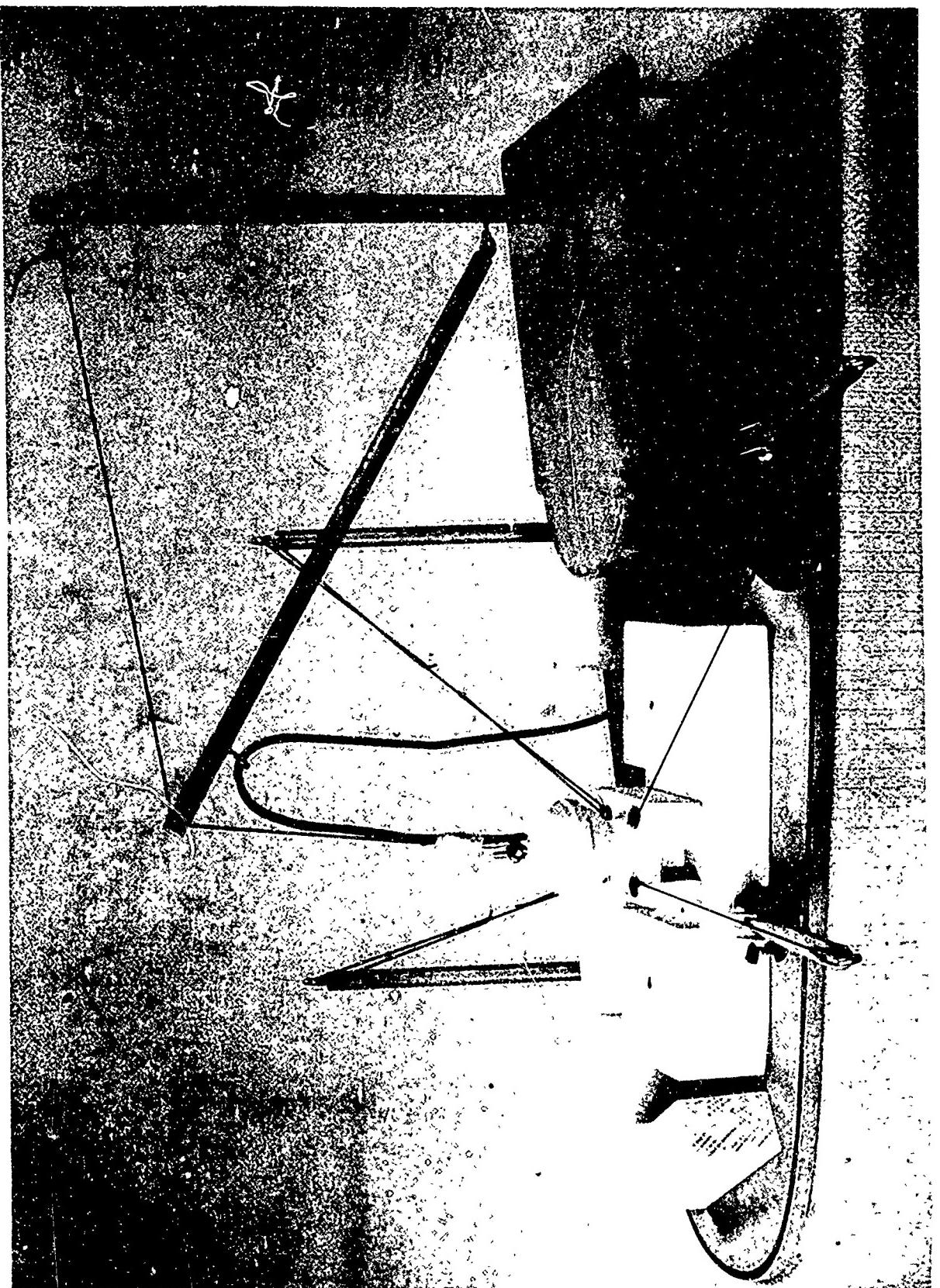
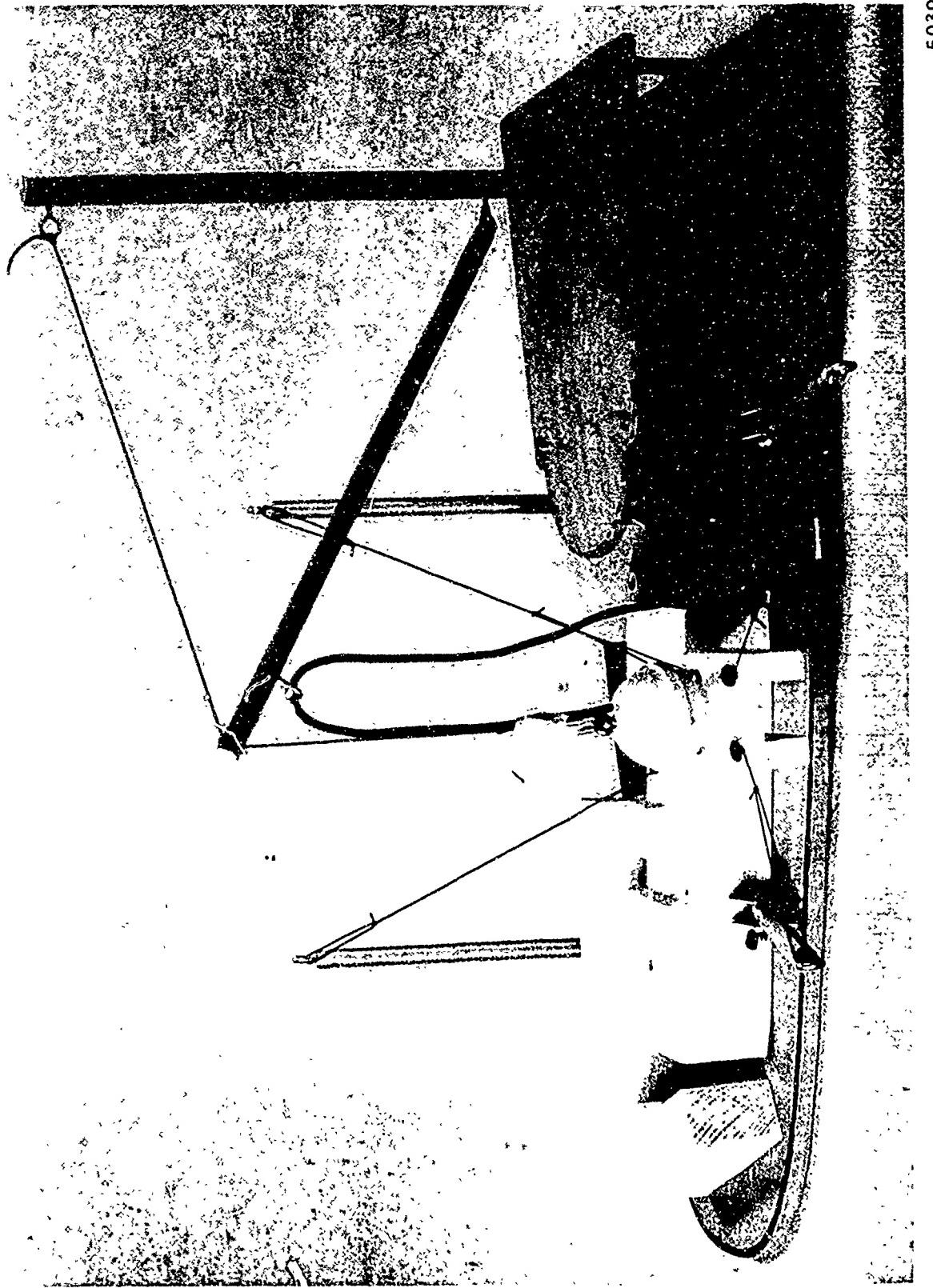


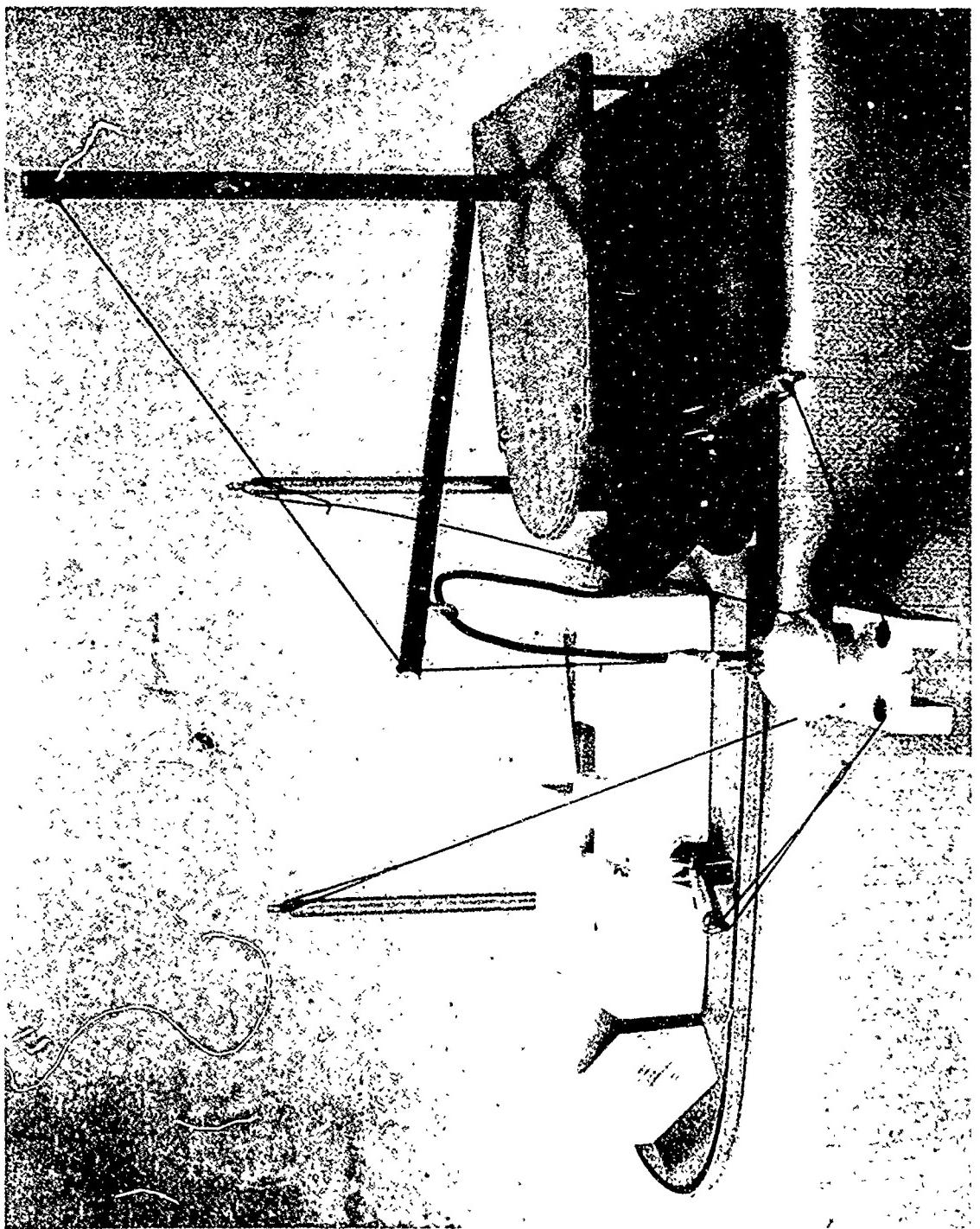
FIGURE 22. FOUR-TUGGER WINCH-BOOM SYSTEM, ASR/ARS CLASS SHIPS, REST POSITION



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FIGURE 23. FOUR-TUGGER WINCH-BOOM SYSTEM, ASR/ARS CLASS SHIPS, INTERMEDIATE POSITION

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FIGURE 24. FOUR-TUGGER WINCH-BOOM SYSTEM, ASR/ARS CLASS SHIPS, DEPLOYMENT POSITION

### Comparison of Feasible Handling Systems

#### Comparison Factors

The final step in determining the most feasible handling system for each of the ship classes was to evaluate and compare each system on certain selected factors. Appropriate weights were given to each factor such that total scores would represent relative feasibility. Each factor was considered to be either Critical, Important, or Fairly Important and to have, respectively, a weight of 3, 2, or 1.

System scores on each factor are a function of the system considered best on that factor. For example, if Systems A, B, and C have respective costs of \$1000, \$2000, and \$3000, then System A is considered best and given a score of 1.00 on the factor cost. Systems B and C have respective system scores on cost of  $1.00 (\frac{1000}{2000}) = 0.50$ , and  $1.00 (\frac{1000}{3000}) = 0.33$ . System scores are then multiplied by the factor weights, yielding system factor scores. Totaling system factor scores yields system feasibility.

Others may consider specific factors to be more or less important than do the authors of this report. If so, the factor weights can be changed accordingly. System scores would remain the same but system factor scores and overall relative system feasibility would be altered.

The following factors and their respective weights were used in determining relative system feasibility:

<u>Factor</u>	<u>Weight</u>
Weight	3
Size	3
Ease of Operation	3
Effect on Ship Stability	3
Commonality With Other Ship Classes	3
Safety	3
Power Requirements	2
Transportability	2
Cost	2
Ease of Installation	2
Manning Requirements	1

#### System Comparison

Weight. Total system weight includes weight of all major handling system components except the SPCC winch, which is used in all systems. For a breakdown of component weights, see Appendix E.

<u>System</u>	<u>Weight, lb</u>	<u>System Score</u>
<u>ATS Class Ships</u>		
A-frame on rails	55,200	1.00
Articulated telescoping crane	56,800	0.97
<u>ASR/ARS Class Ships</u>		
A-frame	36,600	1.00
Articulated telescoping crane	56,800	0.64

Size. Total system size includes envelope volume of all major components except the SPCC winch. For a breakdown of component envelope size, see Appendix F, or the system layout drawings in Appendix K.

<u>System</u>	<u>Size, cu ft</u>	<u>System Score</u>
<u>ATS Class Ships</u>		
A-frame on rails	2310	0.52
Articulated telescoping crane	1210	1.00
<u>ASR/ARS Class Ships</u>		
A-frame	1330	0.91
Articulated telescoping crane	1210	1.00

Ease of Operation. System ease of operation is based on the number of operation steps required for development and recovery. These steps are listed in the operation scenarios in Appendix G.

<u>System</u>	<u>Operation Steps</u>	<u>System Score</u>
<u>ATS Class Ships</u>		
A-frame on rails	30	0.70
Articulated telescoping crane	21	1.00
<u>ASR/ARS Class Ships</u>		
A-frame	24	0.87
Articulated telescoping crane	21	1.00

Effect on Ship Stability. Moment of the entire handling system about the ship's keel determines the effect on the ship's CG. Moments of individual components can be found in Appendix E.

<u>System</u>	Moment About Ships Keel, ft-lb	<u>System Score</u>
<u>ATS Class Ships</u>		
A-frame on rails	1,633,000	1.00
Articulated telescoping crane	1,687,000	0.97
<u>ASR/ARS Class Ships</u>		
A-frame	1,590,000	0.66
Articulated telescoping crane	1,056,000	1.00

Commonality. The articulated telescoping cranes are identical on both ATS and ASR/ARS class ships, while the A-frames are not.

<u>System</u>	<u>Commonality</u>	<u>System Score</u>
<u>ATS Class Ships</u>		
A-frame on rails	No	0.00
Articulated telescoping crane	Yes	1.00
<u>ASR/ARS Class Ships</u>		
A-frame	No	0.00
Articulated telescoping crane	Yes	1.00

Safety. The system that can effect PTC transfer in the least time, using the fewest people, and requiring the least number of man-steps and operator communications will inherently be the safest system. Estimated time of operation, number of men used, steps requiring coordination between men, operator proximity, and number of exposed cables were used as determinants of system safety. Rating of each system on each safety determinant can be found in Appendix H.

<u>System</u>	<u>Safety Score</u>	<u>System Score</u>
<u>ATS Class Ships</u>		
A-frame on rails	16	0.69
Articulated telescoping crane	11	1.00
<u>ASR/ARS Class Ships</u>		
A-frame	16	0.69
Articulated telescoping crane	11	1.00

Power Requirements. System minimum required power is that amount of power used when the system is handling the greatest load at the greatest speed. Handling speed is a function of ship motion, which is a function of PTC location, as previously discussed. The greatest speed required of the handling system is that speed required to completely pull the PTC through the air-sea interface without any relative wave rise on the PTC. The speeds are calculated in Appendix I. Also, at this same location the handling system dynamic loads are greatest. The loads are shown in Appendix D. Systems power requirements are based on these speeds and loads. It should be noted that the actual power requirements of the system would be higher by an amount determined by the efficiencies of the machine elements connecting prime mover to PTC.

<u>System</u>	<u>Minimum Required Power, hp</u>	<u>System Score</u>
<u>ATS Class Ships</u>		
A-frame on rails	116	1.00
Articulated telescoping crane	116	1.00
<u>ASR/ARS Class Ships</u>		
A-frame	95	0.84
Articulated telescoping crane	80	1.00

Transportability. System transportability is a function of total component-envelope volume, system weight, and longest component-envelope dimension. Each will be considered as 1/3 of the transportability factor. Individual component size, volume, and longest dimension can be found in Appendix F. A breakdown of system weights can be found in Appendix E.

<u>System</u>	<u>Volume, cu ft</u>	<u>System Score</u>
<u>ATS Class Ships</u>		
A-frame on rails	2310	0.17
Articulated telescoping crane	1210	0.33
<u>ASR/ARS Class Ships</u>		
A-frame	1330	0.30
Articulated telescoping crane	1210	0.33
<u>System</u>	<u>Weight, lb</u>	<u>System Score</u>
<u>ATS Class Ships</u>		
A-frame on rails	55,200	0.33
Articulated telescoping crane	56,800	0.32

<u>System</u>	<u>Weight, lb</u>	<u>System Score</u>
<u>ASR/ARS Class Ships</u>		
A-frame	36,600	0.33
Articulated telescoping crane	56,800	0.21

<u>System</u>	<u>Longest Envelope Dimension, ft</u>	<u>System Score</u>
<u>ATS Class Ships</u>		
A-frame on rails	40	0.13
Articulated telescoping crane	16	0.33
<u>AST/ARS Class Ships</u>		
A-frame	30	0.18
Articulated telescoping crane	16	0.33

<u>System</u>	<u>Transportability System Score</u>
<u>ATS Class Ships</u>	
A-frame on rails	0.63
Articulated telescoping crane	0.98
<u>ASR/ARS Class Ships</u>	
A-frame	0.81
Articulated telescoping crane	0.87

Cost. System costs are an estimate of total development, fabrication, and hardware costs, i.e., cost of a delivered handling system, not including installation. A complete breakdown of cost and time for each system can be found in Appendix J.

<u>System</u>	<u>Cost, dollars</u>	<u>System Score</u>
<u>ATS Class Ships</u>		
A-frame on rails	107,000	1.00
Articulated telescoping crane	115,000	0.93
<u>ASR/ARS Class Ships</u>		
A-frame	89,000	1.00
Articulated telescoping crane	115,000	0.77

Ease of Installation. Systems are ranked on ease of installation by the amount of cutting and welding required for installation aboard ship.

<u>System</u>	<u>Cutting and Welding, ft</u>	<u>System Score</u>
<u>ATS Class Ships</u>		
A-frame on rails	240	0.10
Articulated telescoping crane	24	1.00
<u>AST/ARS Class Ships</u>		
A-frame	148	0.16
Articulated telescoping crane	24	1.00

Manning Requirements. System manning requirements are determined by the number of man-steps required for deployment and recovery. A breakdown of the man-steps for each operational step of the systems can be found in Appendix G.

<u>System</u>	<u>Man-Steps</u>	<u>System Score</u>
<u>ATS Class Ships</u>		
A-frame on rails	32	0.69
Articulated telescoping crane	22	1.00
<u>ASR/ARS Class Ships</u>		
A-frame	26	0.85
Articulated telescoping crane	22	1.00

#### System Performance Chart

The system performance chart in Table 2 tabulates system performances on each comparison factor.

#### System Comparison Chart

The system comparison chart in Table 3 shows system scores on each comparison factor. Also tabulated are the system factor scores and their total for each system, which represents the systems relative feasibility.

TABLE 2. SYSTEM PERFORMANCE CHART

		A-TS Class Ships		A-Frame on Rafts		A-Frame Telescoping Cranes		AT&T Class Ships		A-Fractured Frame Telescoping Cranes		ASR/ARIS Class Ships		Articulated Telescoping Cranes		ASR/ARIS Class Ships		ASR/ARIS Class Ships		ASR/ARIS Class Ships		ASR/ARIS Class Ships		Four-Tugger Winch-Boom System		ASR/ARIS Class Ships		Four-Tugger Winch-Boom System	
Weight	lb(a)	55,200	56,800	36,600	56,800	56,800	56,800	1,210	1,330	24	21	21	21	21	21	1,633,000	1,687,000	1,590,000	1,056,000	1,056,000	374,000	374,000	374,000	374,000	11,720	11,720			
Size	cu ft(a)	2,310	1,210	1,330	1,330	1,210	1,210	30	30	30	30	30	30	30	30	32	32	32	24	24	24	24	24	24	24	24	24		
Ease of Operation	number of operation steps																												
Effect on Ship Stability	ft-lbs, moment about ship's keel(a)																												
Commonality	No	Yes	No	Yes	No	Yes	No	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes		
Safety	rating: lowest = best	16	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11		
Power Requirements	hp, minimum required	116	116	116	116	116	116	116	116	116	116	116	116	116	116	116	95	95	95	95	95	95	95	95	95	95	95	95	95
Cost	dollars	107,000	115,000	115,000	115,000	115,000	115,000	240	240	240	240	240	240	240	240	89,000	89,000	89,000	148	148	148	148	148	148	148	148	148	148	148
Ease of Installation	ft of cutting and welding																												
Manning Requirement	number of man-steps for operation	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	22	22	22	22	22	22	22	22	22	22	22	22	22

(a) Not including SPCC winch.

TABLE 3. SYSTEM COMPARISON CHART

Factor	Factor Weight	System Score				System Factor Score			
		A-F	ATC	A-F	ATC	ASR/ARS	ATC	A-F	ATC
Weight	3	1.00	0.97	1.00	0.64	3.00	2.91	3.00	1.92
Size	3	0.52	1.00	0.91	1.00	1.56	3.00	2.73	3.00
Ease of Operation	3	0.70	1.00	0.87	1.00	2.10	3.00	2.63	3.00
Effect on Ship Stability	3	1.00	0.97	0.66	1.00	3.00	2.91	1.98	3.00
Commonality	3	0	1.00	0	1.00	0	3.00	0	3.00
Safety	3	0.69	1.00	0.69	1.00	2.07	3.00	2.07	3.00
Power Requirements	2	1.00	1.00	0.84	1.00	2.00	2.00	1.68	2.00
Transportability	2	0.63	0.98	0.81	0.87	1.26	1.96	1.62	1.74
Cost	2	1.00	0.93	1.00	0.77	2.00	1.86	2.00	1.54
Ease of Installation	2	0.10	1.00	0.16	1.00	0.20	2.00	0.32	2.00
Manning Requirements	1	0.69	1.00	0.85	1.00	0.69	1.00	0.85	1.00
System Feasibility Score						17.88	26.64	18.88	25.20

## APPENDIXES

- A - BIBLIOGRAPHY
- B - SUBMERSIBLE OPERATORS QUESTIONNAIRE
- C - SHIP MOTIONS
- D - SHIP MOTION COMPUTER PROGRAM AND PLOTS
- E - SYSTEM WEIGHTS, AND MOMENTS ABOUT KEEL
- F - SYSTEM ENVELOPE VOLUME
- G - SYSTEM OPERATING SCENARIOS
- H - SYSTEM SAFETY RATINGS
- I - DETERMINATION OF MINIMUM PULL-OUT VELOCITY
- J - APPROXIMATE SYSTEM COST AND DELIVERY TIME
- K - SYSTEM LAYOUT DRAWING

## APPENDIX A

BIBLIOGRAPHYSection 1 - Companies

<u>Company</u>	<u>Clue Words</u>
Abell-Howe Company 7747 Van Buren Street Forest Park, Illinois 60130	Crane Overhead Crane
A. C. Hoyle Company Box 589 Iron Mountain, Michigan 49801	Motion Compensation Winches
American Chain and Cable Company Inc. 1110 East Princess Street York, Pennsylvania 17403	Winch
American Hoist and Derrick Company 63 South Robert Street St. Paul, Minnesota 55107	Hoist
Armco National Supply Division Armco Steel Corporation P. O. Drawer H Gainesville, Texas 76240	Crane
Baldwin-Lima-Hamilton Corporation Austin-Western Division Aurora, Illinois 60507	Crane Telescoping Crane
Banbury Manufacturing Corporation 2190 North Main Street Washington, Pennsylvania 15301	Lifting Vacuum Lifting
Barko Hydraulics 310 South 1st Avenue, East Duluth, Minnesota 55802 Division of Lakeshore Body & Equipment Company	Crane Articulating Crane
Beebe Bros. Inc. 2724 Sixth Avenue, South Seattle, Washington 98134	Hoist Winch
Bucyrus-Erie Company General Office South Milwaukee, Wisconsin 53172	Crane Winch
Builders Equipment Company Post Office Box 7143 Phoenix, Arizona 85011	Crane Telescoping Crane

<u>Company</u>	<u>Clue Words</u>
Bushman Material Handling Equipment Company 5135 North Thirty-second Street Milwaukee, Wisconsin 53209 Division of Badger State Gear Company, Inc.	Crane Attachment
Cascade Corporation P. O. Box 20187 Portland, Oregon 97220	Crane Attachment
Conco Inc. Material Handling Division Mendota, Illinois 61342 Subsidiary of H. D. Conkey and Company	Crane Overhead Crane Hoist
Detroit Hoist and Machine Company 6650 Sterling Drive, P. O. Box 686 Warren, Michigan 48090	Crane Hoist Overhead Crane
Dortech Incorporated 737 Canal Street Stamford, Connecticut	Winch
Dresser Crane, Hoist & Tower Division Dresser Industries, Inc. Muskegon, Michigan 49443	Overhead Crane Crane Hoist
Drott Manufacturing Corporation P. O. Box 1087 Wausau, Wisconsin 54401 A Division of J. I. Case Company	Crane Articulating Crane Telescoping Crane
Equitable Equipment Company Incorporated 410 Camp Street New Orleans, Louisiana 70130	Crane
FMC Corporation Link-Belt Speeder Division 1201 Sixth Street, S.W. Cedar Rapids, Iowa 52406	Crane Articulating Crane
Ford Motor Company Birmingham, Michigan 48012	Articulating Crane
Frazer, Inc. 7219 Rampart Street P. O. Box 6295 Houston, Texas 77005	Winch
The Galion Iron Works & Manufacturing Company P. O. Box 647 Galion, Ohio 44833	Crane Telescoping Crane
General Motors Corporation Defense Research Laboratories 5767 Hollister Avenue Goleta, California 93017	Submersible Handling

<u>Company</u>	<u>Clue Words</u>
Gripall Corporation 4343 South Oakley Avenue Chicago, Illinois 60609	Crane Attachment
Grove Manufacturing Company Shady Grove, Pennsylvania 17256 Division of Walter Kidde & Company, Inc.	Crane Telescoping Crane
Heppenstall Company 4620 Hatfield Street Pittsburgh, Pennsylvania 15201	Crane Attachment
Hiab Hydraulics Inc. 3410 Lancaster Pike Wilmington, Delaware 19805	Articulated Crane Crane
Hughes-Keenan Corporation P. O. Box Drawer B Delaware, Ohio 43015 Division of Transairco Inc. Division of United States Air Conditioning Corporation	Crane
Hydraulic Machinery Company 4320 North 124th Street Milwaukee, Wisconsin 53222	Crane
Hydronautics 6338 Lindmar Drive P. O. Box 518 Coleta, California 93017 Subsidiary of Cosmodyne	Motion Compensation Equipment
Ingersoll-Rand 11 Broadway New York, New York 10004	Air Hoist Electrical Hoist
Insley Manufacturing Corporation P. O. Box Nr 167 Indianapolis, Indiana 46206	Crane Articulating Crane
Joe Stine Inc. 6022 Cullen Boulevard P. O. Box 14551 Houston, Texas	Motion Compensation Equipment
John Deere Company Moline, Illinois 61265	Crane Articulating Crane Hoist
Koehring Division of Koehring Company P. O. Box Nr 422 Milwaukee, Wisconsin 53201	Crane Articulating Crane
Lake Shore, Inc. Iron Mountain, Michigan 49801	Winches

<u>Company</u>	<u>Clue Words</u>
Thew-Lorain 1374 East 28th Street Lorain, Ohio 44055 Division of Koehring Company	Crane Telescoping Crane
Lear Siegler, Inc. Vac-U-Lift Division P. O. Box 298 Salem, Illinois 62881	Vacuum Lifting
Markey Machinery Company, Inc. 85 Horton Street Seattle, Washington 98134	Winches
Merrill Brothers 56-02 Arnold Avenue Maspeth, New York 11378	Crane Attachment
Microdot Inc. Equipment Systems Division P. O. Box 95 81 South Main Street Port Deposit, Maryland 21904	Crane
Ocean Systems, Inc. 270 Park Avenue New York, New York 10017 An Affiliate of Union Carbide Corporation and General Precision Equipment Corporation	Swimmer Sled Decompression Chamber Submarine Work Boat Sealift Crane Submersible Handling Articulating Crane
Omark Industries Hydraulic Materials Handling Division P. O. Box 946 Zebulon, North Carolina 27597	Articulating Crane Telescoping Crane Crane
Paceco 2350 Blanding Avenue Alameda, California 94501 A Division of Fruehauf Corporation	Crane
P. A. Radocy & Sons, Inc. East River Road Rossford, Ohio	Telescoping Crane
Parsons, Brinckerhoff, Quade, and Douglas Engineers 165 Broadway New York, New York	Crane
Petersen Engineering Company Inc. 950 Kifer Road Sunnyvale, California	Motion Compensation Equipment
Presray Pawling, New York 12564 Subsidiary of Pawling Rubber Corporation	Vacuum Lifting Equipment

BATTTELLE MEMORIAL INSTITUTE - COLUMBUS LABORATORIES

<u>Company</u>	<u>Clue Words</u>
Programmed and Remote Systems Corporation 899 West Highway 96 St. Paul, Minnesota 55112	Manipulator
Proteus, Inc. 60 Midvale Road Mountain Lakes, New Jersey 07046	Portable Crane Underwater Tools
Renner Manufacturing Company 4810 North 124th Street Milwaukee, Wisconsin 53225	Hoist
Robbins & Myers, Inc. 1345 Lagonda Avenue Springfield, Ohio 45501	Hoist
Scott Midland 11099 Broadway Alden, New York 14004 Division of "Automatic" Sprinkler Corporation of America	Crane Telescoping Crane
Shepard Niles Crane & Hoist Corporation Montour Falls, New York 14865	Hoist
Smith-Berger Mfg. Corporation 3236-16th Avenue Southwest Seattle, Washington 98134	Fairleader
Stal-Laval, Inc. 147 East 50th Street New York, New York 10022	Crane
Stanco Mfg. & Sales, Inc. 800 Spruce Lake Drive P. O. Box 408 Harbor City, California 90710	Crane Articulated Crane Telescoping Crane
Strato-Vacuum Handling Company 3117 North Clybourn Avenue Chicago, Illinois 60618	Vacuum Lifting Equipment
Superior-Lidgerwood-Mondy Corporation Superior, Wisconsin 54880	Hoist
Unit Crane & Shovel Corporation 6411 West Burnham Street Milwaukee, Wisconsin 53219	Crane
Vacuum Concrete Corporation of America 6111 Lancaster Avenue Philadelphia, Pennsylvania 19151	Vacuum Lifting Equipment
Vickers Limited Barrow Shipbuilding Works P. O. Box Nr 6 Barrow-in-Furness Lancashire, England	Submersible Handling

<u>Company</u>	<u>Clue Words</u>
Ware Machine Works, Inc. Ware, Massachusetts 10182	Crane Articulating Crane
Warner & Swasey Company 5701 Carnegie Avenue Cleveland, Ohio 44103	Crane Articulating Crane Telescoping Crane

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01041	Hahn, O. W., "Boom Stabilizing and Safety Control Apparatus", U. S. Patent 3,097,749, July 16, 1963.	Motion Compensation
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01053	Bartoli, C., "Derrick Devices for Lifting the Goods on the Ships", U. S. Patent 3,084,807, April 9, 1963.	Cargo Handling
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01059	Banks, W. L., "Cargo Hoisting Apparatus", U. S. Patent 2,830,710, April 15, 1958.	Cargo Handling
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01066	Evans, E. C., and Shipek, C. J., "Method and Apparatus for Depth Regulation", U. S. Patent 3,088,710, May 7, 1963.	Motion Compensation
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01072	Scaperotto, C. A., "Pipe-Lifting Attachment for Excavating Equipment", U. S. Patent 3,472,401, October 14, 1969.	Crane Attachment
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01075	Mork, G. W., "Rocker Support for Bucket Attachment", U. S. Patent 3,462,029, August 19, 1969.	Crane Attachment Excavator
01076	Thomson, J. S., "Anti-Pendulum Crane Rigging", U. S. Patent 3,191,779, June 29, 1965.	Motion Compensation Cranes
01077	Frank, W., "The Heave Damping Coefficient of Bulbous Cylinders, Partially Immersed in Deep Water", Journal of Ship Research, September 1967, pp 151-153.	Submersible Handling
01079	Patterson, J. C., "Method to Prevent a Load From Swinging During Hoisting and Turning of a Crane", U. S. Patent 3,065,862, November 27, 1962.	Motion Compensation Cranes
01080	Wilkinson, A. H., "Jackknife Boom", U. S. Patent 3,170,574, February 23, 1965.	Cranes
01081	Crittenden, G. H., and Mills, A. E., "Anti-Sway Device", U. S. Patent 3,375,938, April 2, 1968.	Motion Compensation
01082	Newman, W. M., and Forster, G. A., "Control Systems", U. S. Patent 3,351,213, November 7, 1967.	Motion Compensation
01083	Weber, S. J., "Crane Having a Principal Mast and a Pivotable Auxiliary Jib", U. S. Patent 3,338,428, August 29, 1967.	Crane Articulating Crane
01084	Wright, L. A., "Articulating Crane", U. S. Patent 3,325,018, June 13, 1967.	Articulating Crane
01085	Bradshaw, W. K., "Cargo Handling Apparatus", U. S. Patent 3,375,937, April 2, 1968.	Cargo Handling
01086	Thaeter, H., "Method and Apparatus for Operating Loading Equipment for Ships", U. S. Patent 3,106,300, October 8, 1963.	Cranes Cargo Handling
01087	Iwashita, K., Yoshimura, M., Miyazaki, S., and Tamaki, K., "On-Board Loading and Unloading System", U. S. Patent 3,481,495, December 2, 1969.	Cargo Handling
01089	Black, R. W., "Apparatus for Lightering Cargo Vessels", U. S. Patent 3,168,955, February 9, 1965.	Cargo Handling

<u>Accession Number</u>	<u>Reference</u>	<u>Clue Word</u>
01090	Olson, L. O., "Apparatus and Method for Recovering Floating Objects", U. S. Patent 3,262,585, July 26, 1966.	Submersible Handling
01091	Novotny, C. F., "Braked Ball and Socket Support for Bucket Attachment", U. S. Patent 3,493,125, February 3, 1970.	Crane Attachment Excavator
01092	Hainer, W. H., and Sullivan, R. J., "Floor Mounted Manipulator Support Structure", U. S. Patent 3,268,092, August 23, 1966.	Manipulator
01093	Stratton, R. R., "Crane Having Articulated Boom", U. S. Patent 3,253,716, May 31, 1966.	Articulating Crane
01094	Billings, R. O., "Excavators", U. S. Patent 3,143,229, August 4, 1964.	Crane Attachment Excavators
01095	Vik, A. M., "Tilting Mechanism for a Lifting Implement", U. S. Patent 3,426,929, February 11, 1969.	Crane Attachment
01096	Orloff, G., "Mechanical Handling Apparatus", U. S. Patent 3,241,687, March 22, 1966.	Manipulator
01097	Heikkinen, L. L., "Materials Positioning Fork", U. S. Patent 3,301,587, January 31, 1967.	Cargo Handling
01098	Allard, P.J.T., "Retractable Unloader", U. S. Patent 3,091,353, May 28, 1963.	Crane Attachment
01099	Martin, R. W., and Spears, J. R., "Hydraulically Actuated Bucket Closing Means", U. S. Patent 3,479,077, November 18, 1969.	Crane Attachment
01100	Matheisel, R. A., Matson, C. H., and Johnston, J. G., "Stores Loading at Sea", U. S. Patent 3,069,028, December 18, 1962.	Cargo Handling Submersible Handling
01101	Crenshaw, R. S., "Constant Tension Device for Boat Falls", U. S. Patent 2,948,512, August 9, 1960.	Motion Compensation Constant Tension Hoisting Equipment
01102	Nelson, R. A., "Tension Control Device", U. S. Patent 3,150,860, September 29, 1964.	Motion Compensation Constant Tension
01103	Hurst, G. P., "Anti-Sway Linkage for Container Engaging Means", U. S. Patent 3,241,686, March 22, 1966.	Motion Compensation
01104	Parnell, P. E., "Dynamic Load Compensation System", U. S. Patent 3,343,810, September 26, 1967.	Motion Compensation Constant Tension Cable
01105	Patterson, J. C., "Automatic Tension System for Fueling at Sea", U. S. Patent 2,839,021, June 17, 1958.	Motion Compensation Constant Tension
01106	Garnett, E. V., "Workman's Cage or Aerial Basket", U. S. Patent 3,196,979, July 27, 1965.	Crane Attachment
01107	Gercke, E., "Apparatus for Damping Pendulum Motions of the Load Suspended From a Lifting Machine", U. S. Patent 2,916,162, December 8, 1959.	Motion Compensation

<u>Accession Number</u>	<u>Reference</u>	<u>Clue Word</u>
01108	Woodeson, W. A., and Midgley, W., "Means for the Launching and Recovery of Water-Borne Craft From and to Ships", U. S. Patent 2,187,714, January 16, 1940.	Crane
01109	Melton, D. F., "Vehicle-Mounted Manipulator", U. S. Patent 3,043,448, July 10, 1962.	Manipulator
01110	Boutelle, A., "Underwater Manipulator", U. S. Patent 3,312,496, April 4, 1967.	Manipulator
01111	French, J. L., Termont, C. G., and Gunn, J. C., "Loader Bucket Leveling Control", U. S. Patent 3,032,215, May 1, 1962.	Motion Compensation
01112	Wilder, L. N., "Underwater Lowering Device", U. S. Patent 2,981,074, April 25, 1961.	Submersible Handling Cable
01113	Rees, W. A., "Personnel or Object Transfer Apparatus and Method", U. S. Patent 2,874,855, February 24, 1959.	Submersible Handling Cargo Handling
01114	Pristach, M. R., "Load Transfer System, Especially for Ships at Sea", U. S. Patent 2,942,740, June 28, 1960.	Cargo Handling
01115	Meyer, R. L., "Constant Relationships Hoist Drive System", Westinghouse Electric Corporation, March, 1965, AD 623 400.	Constant Tension Motion Compensation Hoist
01116	O'Brien, J. T., and Maacisaac, "Problems Pertinent to Lowering and Raising Loads in the Ocean", U. S. Naval Civil Engineering Laboratory, June, 1964, AD 444 104, 15 pp.	Submersible Handling
01117	Beck, H. C., and Gonda, A., "Outfitting of the USNS S. W. Gibbs T-AGOR-1", Hudson Laboratories of Columbia University, September, 1968, Tech Report 157, AD 688 851, 74 pp.	Hoist Winch Crane A-Frame
01119	Shipek, C. J., and Evans, E. C., "Depth Regulation of Lowered Oceanographic Equipment", U. S. Navy Electronics Laboratory, March 27, 1964, Division Report 1215, AD 600 187.	Motion Compensation Hoist Winch
01120	Fabachnikov, L. D., and Bugoslavskiy, Yu. K., "Device for Automatic Balancing of Hydraulic Jib Crane", U. S. Army Mobility Equipment Center, T-1897-67, February, 1967, AD 648 404.	Crane Motion Compensation
01121	Dabrowski, A., Slesarenko, N., Zurichenko, A., and Vvedenskiy, D., "Materials Handling Equipment", July 30, 1969, ATD Report 69-89.	Cargo Handling Cranes
01122	Burroughs, L. R., and Ralsten, H. E., "Design Study of Heavy Lift Helicopter External Load Handling System", U. S. Army Aviation Material Laboratories, USAVLABS Tech Rpt 67-46, Issue AD 828 283, November, 1967, 270 pp.	Motion Compensation Hoist Cargo Handling
01123	"Rough Terrain Crane", Military Engineering Experimental Establishment, January, 1967, Report 1008, 55 pp.	Crane
01124	"Q-2A Drone Retrieval From Water by Helicopter", September 21, 1959, Issue ADC/73AD 58-3, 11 pp.	Winch Motion Compensation

<u>Accession Number</u>	<u>Reference</u>	<u>Class Work</u>
01125	"Heavy Duty Mast, Vertically Erected, 75 Foot , U. S. Army Electronics Research and Development Laboratory, First Quarterly Report 16 June - 15 September, 1962, ARDE 6625-Q1, Report 1, p 51.	Crane
01126	Scharff, L., and Harvey, C. W., "Crane Tilting Indicating System", U. S. Naval Gun Factory, June 9, 1954, NAVORD Tech Report 477C, NGT-T-35-54, 6 pp.	Crane Motion Compensation
01128	Huggett, W. S., "Technique for Mooring Underwater Instruments on the Continental Shelf", MTS Journal, November - December, 1969, Vol 3, Issue 6, pp 57-64.	A-Frame
01129	"Development of Supply Craft - A Materials Handling System for Mobile Supply Barges (YFNB and Similar Types), U. S. Naval Supply Research and Development Facility, 5.30012 (Report 3), AD 800 946L.	Cargo Handling
01130	Flemming, N. C., "Functional Requirements for Research/Work Submersibles", The Aeronautical Journal of the Royal Aeronautical Society, February, 1968, Vol 72, pp 123-131.	Submersible
01131	Brown, A. S. and Beniston, P. T., "Cargo Handling Equipment for Dry Cargo Vessels", The Institute of Marine Engineers Transactions, 1964, Vol 76, pp 1-19.	Cargo Handling Cranes Winches
01132	Murray, D. J., "Multi-Rope Friction Hoisting". The Canadian Mining and Metallurgical Bulletin, February, 1965, pp 206-212.	Hoists
01139	"Winches and Cables for Oceanography", Undersea Technology, September, 1969, p 37.	Submersible Handling Winches Cables
01140	"Wave Monitor Synchronizes Dangling Cargo and Heaving Ships", Machine Design, September 1, 1966, p 32.	Crane Transloader Motion Compensation
01141	Muckle, W., "A Note on the Buoyancy of a Ship Among Waves", Shipping World and Shipbuilder, December 2, 1965, pp 572-578.	Ship Motion
01142	McKenna, H. A., "Giant New Winch Built to Pull Undersea Pipe", Undersea Technology, September, 1969, pp 40-42.	Winch
01143	"Undersea 'Elevator' Aids Offshore Oil Exploration", Machine Design, June 12, 1969, p 54.	Submersible Handling A-Frame
01144	"Winches and Deck Handling Systems Crucial to Scientific Work at Sea", Undersea Technology, September, 1969, pp 34-35.	Winches A-Frame
01145	Covey, C. W., "Deck Handling Equipment and Electrical Systems", Naval Engineers Journal, August, 1966, pp 685-692.	Hoist Winch Crane
01146	Delauze, H. G., "Diving in the European Community", Undercurrents, July, 1969, pp 14-16.	Diving Submersible Handling
01147	Dyment, R., "Cachalot Diving System Aids Repairs on Utility Dam", Compressed Air Magazine, June, 1966, pp 4-8.	Submersible Handling

<u>Accession Number</u>	<u>Reference</u>	<u>Clue Word</u>
01148	Holm, C. H., "Rigging Materials and Techniques", Handbook of Ocean and Underwater Engineering, McGraw-Hill Book Company, New York, 1969, pp 4-75 to 4-89.	Fairleader Cargo Handling A-Frame
01149	"Activated Tank Stabilizer", Shipbuilding and Shipping Record, August 11, 1966, pp 192-193.	Motion Compensation Ship Motion
01150	Patton, K. T., "Tables of Hydrodynamic Mass Factors for Translational Motion", Winter Annual Meeting of the American Society of Mechanical Engineers, Chicago, Illinois, November 7-11, 1965, 7 pp.	Motion Compensation
01151	De La Riviere, W. D., "Buoy Tending Equipment on Canadian Coast Guard Ships", Defense Research Establishment, Toronto, December, 1967, DRET RPT Nr 683, AD 831 321, 43 pp.	Lifting
01152	Williford, J. R., "Special Problems in Helicopter Handling Qualities as Influenced by Anti-Submarine Warfare Requirements", AGARD Conference Proceedings, January, 1966, Nr 7, N67-15205, pp 473-478.	Motion Compensation
01153	"Shipboard Cranes and Bracing Gear-Evaluation of Cargo Handling Equipment in the Liberty Ship Program - Progress Report Nr 1", January, 1957, AD 470 895, 26 pp.	Cargo Handling Cranes
01154	Muga, B. J., "Construction Equipment for Handling Heavy Loads in the Ocean", U. S. Naval Civil Engineering Laboratory, March, 1966, TN-760, 117 pp.	Submersible Handling
01155	"Overspeed Sensor Redesign Study - Phase 1 Atlas 'F' Missile Lifting System", General Dynamics/Astronautics, August 12, 1963, TCP-1623, Rpt Nr 63-0684, AD 829 695, 64 pp.	Motion Compensation
01156	Sherwood, G. E., and Beard, W. H., "Polar Transportation Equipment - Hydraulic Cranes for Cargo Vehicles", U. S. Naval Civil Engineering Laboratory, September, 1965, Technical Note N-770, AD 472 837.	Cranes Cargo Handling
01158	Sarchin, T. H., and Goldberg, L. L., "Stability and Buoyancy Criteria for U. S. Naval Surface Ships", Annual Meeting of the Society of Naval Architects and Marine Engineers, New York, New York, November 15-16, 1962.	Ship Motion
01159	Canham, H.J.S., Cartwright, D. E., Goodrich, G. J., and Hogben, N., "Seakeeping Trials on O.W.S. Weather Reporter", Spring Meeting of the Royal Institution of Naval Architects, March 29, 1962, London.	Ship Motions
01339	Dunstone, D. E., "Commercial Handling Equipment Survey for Equipment With Possible Application to Missile System Launcher Reloaders", U. S. Army Missile Command, Rpt Nr PL-TN-69-3, August 1969, AD 692 309, 73 pp.	Submersible Handling
01340	Vandiver, J. K., "Dynamic Analysis of a Launch and Recovery System for a Deep Submersible", Woods Hole Oceanographic Institution, May, 1969, AD 699 175, 75 pp.	Submersible Handling
01341	"Equipment Modification Report - Sonar Hoist Mechanism Group (VDS) AN/SQA-10", Illinois Tool Works Inc., November 1, 1965, 17 pp.	Hoist

<u>Accession Number</u>	<u>Reference</u>	<u>Clue Word</u>
01342	Snyder, A. E., "Winches and Deck Machinery", In Handbook of Ocean and Underwater Engineering, McGraw-Hill Book Co., New York, 1964, pp 4-90 to 4-123.	Winches
01343	Bankovich, M. P., "Stabilizing Bar for Lifting and Lowering Systems Used With Submersible Objects", U. S. Patent 3,518,837, July 7, 1970.	Submersible Handling Motion Compensation

Section 3 - Index to Bibliography by Clue Word

<u>Clue Word</u>	<u>Reference</u>
A-Frame	01117, 01128, 01143, 01144, 01148
Articulating Crane	Barko Hydraulics Drott Manufacturing Corporation FMC Corporation Ford Motor Company Hiab Hydraulics, Inc. Insley Manufacturing Corporation John Deere Koehring Company Ocean Systems, Inc. Omark Industries Stanco Mfg and Sales Inc. Warner & Swasey Co. Ware Machine Works Inc.
Cargo	01104, 01139
Cargo Handling	00576, 01048, 01049, 01052, 01053, 01056, 01057, 01059, 01078, 01085, 01086, 01087, 01088, 01089, 01097, 01100, 01113, 01114, 01121, 01122, 01129, 01131, 01148, 01153, 01156, 01157
Constant Tension	00625 11048, 01101, 01102, 01104, 01105, 01115
Crane	Abell-Howe Company Armco Steel Corporation Baldwin-Lima-Hamilton Corporation Barko Hydraulics Bucyrus-Erie Company Builders Equipment Company Conco Inc. Detroit Hoist and Machine Company Dresser Industries Inc. Drott Manufacturing Corporation Equitable Equipment Company, Inc. FMC Corporation Galion Iron Works and Manufacturing Company Grove Manufacturing Company Hiab Hydraulics Inc. Hughes-Keenan Corporation Hydraulic Machinery Company Insley Manufacturing Corporation John Deere Koehring Company Microdot Inc. Ocean Systems Inc. Omark Industries Paceco Parsons, Brinckerhoff, and Douglas Engineers Proteus, Inc. Scott Midland Stal-Laval Inc. Stanco Mfg and Sales, Inc. Unit Crane and Shovel Corporation Ware Machine Works Inc.

<u>Clue Word</u>	<u>Reference</u>
Crane (Cont.)	Warner & Swasey Co. 00248, 00249, 00250, 00287, 00299, 00446, 00469, 00516, 00576, 00826, 01041, 01042, 01043, 01044, 01046, 01048, 01052, 01054, 01055, 01057, 01058, 01060, 01061, 01062, 01063, 01065, 01067, 01076, 01078, 01079, 01080, 01083, 01084, 01086, 01088, 01108, 01117, 01120, 01121, 01123, 01125, 01126, 01131, 01140, 01145, 01153
Crane Attachment	Bushman Material Handling Equipment Company Cascade Corporation Gripall Corporation Heppenstall Company Merrill Brothers 01045, 01051, 01070, 01071, 01072, 01073, 01074, 01075, 01091, 01094, 01095, 01098, 01099, 01106
Derrick	00576, 00659, 00660, 01053, 01054
Excavator	01091
Fairleader	Smith-Berger Manufacturing Corporation 01148
Hoist	American Hoist and Derrick Company Beebe Bros., Inc. Conco Inc. Detroit Hoist and Machine Company Dresser Industries, Inc. Ingersoll-Rand John Deere Renner Manufacturing Company Robbins and Myers, Inc. Shepard Niles Crane and Hoist Corporation Superior-Lidgerwood Corporation 00659, 00664, 01059, 01069, 01101, 01115, 01117, 01119, 01122, 01132, 01145
Lifting	Banbury Manufacturing Corporation 01151
Manipulator	Programmed and Remote Systems Corporation 00587, 00595, 00648, 00741, 00802, 00909, 00927, 00958, 01068, 01092, 01094, 01096, 01109, 01110
Motion Compensation	Hydronautics Joe Stine, Inc. Petersen Engineering Company, Inc. 00287, 01041, 01042, 01043, 01046, 01047, 01050, 01051, 01052, 01062, 01066, 01067, 01076, 01078, 01079, 01081, 01082, 01101, 01102, 01103, 01104, 01105, 01107, 01111, 01115, 01119, 01120, 01122, 01124, 01126, 01140, 01149, 01150, 01152, 01155
Overhead Crane	Abell-Howe Company Conco Inc. Detroit Hoist and Machine Company Dresser Industries, Inc.
Salvage	00664, 00587

<u>Clue Word</u>	<u>Reference</u>
Ship Motion	01141, 01149, 01158, 01159
Submersible	00446, 00458, 00516, 00587, 00637, 00826, 00927, 00958, 01008, 01019, 01130
Submersible Handling	General Motors Corporation Ocean Systems, Inc. Vickers Ltd. 00446, 00516, 00623, 00826, 01063, 01064, 01077, 01090, 01100, 01112, 01113, 01116, 01139, 01143, 01146, 01147, 01154
Telescoping Crane	Baldwin-Lima-Hamilton Corporation Builders Equipment Company Drott Manufacturing Corporation Galion Iron Works and Manufacturing Company Grove Manufacturing Company Koehring Company Omark Industries P. A. Radocy and Sons, Inc. Scott Midland Stanco Mfg and Sales, Inc. Warner & Swasey Co. 01065
TV Camera	01068
Vacuum Lifting	Banbury Manufacturing Corporation Lear Siegler, Inc. Presray Strato-Vacuum Handling Company Vacuum Concrete Corporation of America
Winch	A. C. Hoyle Company American Chain and Cable Company, Inc. Beebe Bros., Inc. Bucyrus-Erie Company Dortech Incorporated Frazer, Inc. Lake Shore Inc. Markey Machinery Company, Inc. 01064, 01117, 01119, 01124, 01131, 01139, 01142, 01144, 01145

APPENDIX B

SUBMERSIBLE OPERATORS QUESTIONNAIRE

Questionnaire

Directions: Check the appropriate box in each section. If you have more than one handling system use a unique set of marks for each (✓ or X). Be specific on any explanations — feel free to elaborate. Please return this form in the accompanying envelope.

Questions:

(1) What type of support ship is used in deployment and recovery of your submersible?

- Salvage tug
- Oil derrick
- Ship with centerwell
- Catamaran
- Barge
- Other — please explain

(2) In what Sea State are you capable of deployment and recovery?

- 0
- 1-2
- 3
- Over 3

(3) What is the main support of your handling system?

- Ship's boom
- Overhead crane
- Portable crawler crane
- A-frame
- Other — please explain

(4) From what point on ship is your submersible lowered and raised?

- Midship
- Stern
- Centerwell
- Sternwell
- Other — please explain

(5) What do you use to compensate for undesired ship and sea motion during deployment and recovery?

- Nothing
- Constant tension winch
- Other — please explain

We would also appreciate receiving any literature and/or specifications on your handling system.

## B-3 and B-4

TABLE B-1. QUESTIONNAIRE RESPONSES

Company	Response	Submersible	Support Ship	Sea State	Main Support	Deployment Recovery Point	Motion Compensation	Remarks
Marine Technology, Inc.	No							
Lockheed Missiles and Space Company	No							
Woods Hole Oceanographic Institution	No							
North American Aviation, Ocean Systems	No							
Hydrotech Co.	No							
Westinghouse Corp. - Underseas Division	No							
General Dynamics, Electric Boat Division	No							
International Hydrodynamics Co., Ltd.	Yes	Places	Oil derrick or barge	1-2		Stern	None	Little success with any handling system; stern deployment best because of ship mobility
Grumman Aircraft Engineering Group	Yes	Franklin	Converted mine sweeper	3	Towed		None	Towed to point of operation; beach crane for deployment and recovery
Makai Range, Inc.	Yes		Submersible Pontoon	Over 3			None	Submarine operates from platform 50 to 75-foot depth
Institut Océanographique, Monaco	Yes	Diving Saucer 350 Puce 500	Converted mine sweeper or barge	3 (normal) Over 3	Other (1)	Stern	Other (2)	(1) Hydraulic articulated crane-head can reach sea level; diver places sling fixed to submarine, diver attaches to crane hook (2) Pilot can follow (and prevent) ship movement with fast-motion capability of crane; twin screws and rudders of ship enable maneuverability to keep favorable position on wind and sea
International Underwater Contractors, Inc.	Yes		Salvage tug Centerwell ship Catamaran Barge		Ship's boom portable crawler crane	Stern	None	
AC Electronics, Defense Research Laboratories	Yes	DOWB	Converted mine sweeper	3	A-frame	Stern	Operator synchronization	
USN Ordnance Test Station	Yes	CURV II CURV III Deepview DSRV 1 DSRV 2	Light tug Barge Barge Barge Barge	3	Overhead crane	Midship Midship Stern Stern	Constant-tension winch	Would like to use catamaran with twin submerged hulls to cut down ship motion
Ocean Systems, Inc.	Yes	Submersible decompression chamber	All types	Over 3	Single davit		None	Best deployment location selected on basis of space available
Sun Shipbuilding and Drydock Co.	Yes	Guppy	Typical offshore supply boat	3	Portable crawler crane	Stern	None	Welded down hydraulic backhoe type crane
Undersea Engineering, Inc.	Yes	Sheardiver	Offshore supply boat	Over 3	A-frame	Stern	Constant-tension winch	
French Navy	Yes		1,500-ton ship	1-2	Other	Midship	None	Hydraulic crane catches submarine directly on surface

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## APPENDIX C

SHIP MOTIONSDDS-I Personnel Transfer Capsule (PTC) Handling TaskPerformance Requirements

TABLE C-1. SHIP MOTIONS

Ship Class	Dimensions LBP x B x D Full Load Displacement	Roll					Pitch					Heave				
		Period, sec	Amplitude, $\pm$ deg				Period, sec	Amplitude, $\pm$ deg				Period, sec	Amplitude, $\pm$ ft			
			SS 2	3	4	5		SS 2	3	4	5		SS 2	3	4	5
ARS-6	213' x 41' x 14.6' 1,950 tons	11.1	3.4	5.8	7.8	10.4	4.8	1.5	2.7	3.7	5.4	4.7	1.5	2.6	3.9	6.2
ASR-13	251' x 44' x 15' 2,290 tons	11.0	3.0	5.5	7.5	10.0	5.0	1.4	2.6	3.6	5.3	4.7	1.3	2.3	4.0	6.2
ATS-1	264' x 50' x 15' 3,050 tons	11.0	3.0	5.0	6.5	9.0	6.0	1.3	2.0	3.0	4.0	6.0	1.2	2.2	4.0	6.0

TABLE C-2. SEA-STATE DATA(a)

Sea State	Significant Wave Height, $\tilde{H}_{1/3}$ , ft (double amplitude)	Wind Velocity, knots
2	2.2	12
3	4.6	16
4	6.9	19
5	10.0	22

- (a) Taken from Mark's Sea-State Chart. The handling system shall be designed for satisfactory and safe operation in sea-state 3 conditions as defined above. Reference (1) to NAUSEC Ser. 152-6162.

Dynamic Load Factors (DLF)

The dynamic load factors for the longitudinal (x), transverse (y), and vertical (z) directions are expressed as,

$$DLF_x = \frac{R_x}{W} = \sin \phi + \frac{4\pi^2 \phi^2}{gT_p^2} l + \frac{4\pi^2 \phi}{gT_p^2} v$$

$$DLF_y = \frac{R_y}{W} = \sin \theta + \frac{4\pi^2 \theta^2}{gT_R^2} t + \frac{4\pi^2 \theta}{gT_R^2} v$$

$$DLF_z = \frac{R_z}{W} = \cos \theta \cos \phi + \frac{4\pi^2}{gT_H^2} Y_H + \frac{4\pi^2 \theta}{gT_R^2} t + \frac{4\pi^2 \phi}{gT_p^2} v$$

where

$v$  = vertical distance from KG (feet) to equipment CG

$t$  = transverse distance from ship centerline (feet) to CG

$l$  = longitudinal distance from midships (feet) to CG

$\phi$  = pitch amplitude ( $\pm$  rad.)

$\theta$  = Roll amplitude ( $\pm$  rad.)

$Y_H$  = Ship heave amplitude ( $\pm$  feet)

$W$  = Weight of stowed equipment

$R_x$  = Max. load in longitudinal direction

$R_y$  = Max. load in transverse direction

$R_z$  = Max. load in vertical direction

$g$  = acceleration of gravity = 32.17 ft/sec<sup>2</sup>

TABLE C-3. DLF'S FOR ARS-6 AND ASR-13 CLASS SHIPS

Sea State	Ship	DLF
2	ARS-6	$DLF_x = .026 + .000036 \ell + .0014 v$
		$DLF_y = .059 + .000035 t + .00059 v$
		$DLF_z = 1.08 + .00059 t + .0014 \ell$
	ASR-13	$DLF_x = .024 + .000029 \ell + .0012 v$
		$DLF_y = .052 + .000028 t + .00053 v$
		$DLF_z = 1.07 + .00053 t + .0012 \ell$
3	ARS-6	$DLF_x = .047 + .00012 \ell + .0025 v$
		$DLF_y = .10 + .00010 t + .0010 v$
		$DLF_z = 1.14 + .001 t + .0025 \ell$
	ASR-13	$DLF_x = .045 + .0001 \ell + .0022 v$
		$DLF_y = .096 + .000093 t + .00097 v$
		$DLF_z = 1.12 + .00097 t + .0022 \ell$
4	ARS-6	$DLF_x = .064 + .00022 \ell + .0034 v$
		$DLF_y = .136 + .00018 t + .0014 v$
		$DLF_z = 1.20 + .0014 t + .0034 \ell$
	ASR-13	$DLF_x = .063 + .00019 \ell + .0031 v$
		$DLF_y = .13 + .00017 t + .0013 v$
		$DLF_z = 1.21 + .0013 t + .0031 \ell$
5	ARS-6	$DLF_x = .094 + .00047 \ell + .005 v$
		$DLF_y = .18 + .00033 t + .0018 v$
		$DLF_z = 1.32 + .0018 t + .005 \ell$
	ASR-13	$DLF_x = .092 + .00042 \ell + .0045 v$
		$DLF_y = .174 + .00031 t + .0018 v$
		$DLF_z = 1.32 + .0018 t + .0045 \ell$

TABLE C-4. DLF'S FOR ATS-1 CLASS

Sea State	DLF
	$DLF_x = .023 + .000017 \lambda + .00077 v$
2	$DLF_y = .052 + .000028 t + .00053 v$ $DLF_z = 1.04 + .00053 t + .00077 \lambda$
	$DLF_x = .035 + .000042 \lambda + .0012 v$
3	$DLF_y = .087 + .000077 t + .00088 v$ $DLF_z = 1.07 + .00088 t + .0012 \lambda$
	$DLF_x = .052 + .000093 \lambda + .0018 v$
4	$DLF_y = .113 + .00013 t + .0012 v$ $DLF_z = 1.13 + .0012 t + .0018 \lambda$
	$DLF_x = .07 + .00017 \lambda + .0024 v$
5	$DLF_y = .16 + .00025 t + .0016 v$ $DLF_z = 1.19 + .0016 t + .0024 \lambda$

Stability Status

ASR-6 — Status 2 (compensation required for weight and KG)

ASR-13 — Status 3 (compensation required for KG)

ATS-1 — New Construction (status not available)

## APPENDIX D

SHIP MOTION COMPUTER PROGRAM AND PLOTS

```

PROGRAM WAVE(INPUT,OUTPUT,PLOT,TAPES=INPUT,TAPE6=OUTPUT,
1           TAPE99=PLOT)
C
000003      DIMENSION D(2010),V(2010),FU(2010),FA(2010),T(2010),R(4),TR(4),
1           P(4)    ,TP(4)   ,H(4)    ,TH(4)
C
C
000003      DATA  TPI/6.28318530/
000003      DATA  R /0.,2.7,0.,2.3/
000003      DATA  TR /11.0,11.0,11.0,11.0/
000003      DATA  P /4.8,3.0,6.2,4.3/
000003      DATA  TP /6.0,6.0,5.0,5.0/
000003      DATA  H /2.2,2.2,2.3,2.3/
000003      DATA  TH /6.0,6.0,4.7,4.7/
C
C
C
C
000003      READ(5,99) TIME,DELTAT
000013      99 FORMAT(2F10.0)
C
000013      INTERV=TIME/DELTAT+1,
000017      XLEN=TIME/10.
C
000021      DO 10 I=1,4
C
000022      T=DELTAT
C
000024      DO 20 J=1,INTERV
C
000025      TERM1=R(I)*SIN(TPI/TR(I)*T(J))
000034      TERM2=P(I)*SIN(TPI/TP(I)*T(J))
000043      TERM3=H(I)*SIN(TPI/TH(I)*T(J))
000052      TERM4=2.30*SIN(TPI/4.600*T(J))
C
000060      TERM5=(TPI/TR(I))*TERM1
000063      TERM6=(TPI/TP(I))*TERM2
000065      TERM7=(TPI/TH(I))*TERM3
000067      TERM8=(TPI/4.600)*TERM4
C
000072      TERM9 =(TPI/TR(I))*TERM5
000075      TERM10=(TPI/TP(I))*TERM6
000077      TERM11=(TPI/TH(I))*TERM7
000101      TERM12=(TPI/4.600)*TERM8
C
000104      D(J)=TERM1+TERM2+TERM3+TERM4
000111      V1 =TERM5+TERM6+TERM7
000114      V(J)=V1+TERM8
000117      A =TERM9+TERM10+TERM11
C
000122      FA(J)=18000.* (1.+A/32.2)
C
000126      FU(J)=600.+17.98*V1*V1+18000.*A/32.2

```

```

000134      C      T(J+1)=T(J)+DELTAT
000137      C      2^ CONTINUE
000142      C      D(INTERV+1)=-25.0
000143      C      V(INTERV+1)=-25.0
000144      C      FU(INTERV+1)=15000.
000145      C      FA(INTERV+1)=15000.
000147      C      T(INTERV+1)=0.
000150      C      D(INTERV+2)=5.0
000151      C      V(INTERV+2)=5.0
000152      C      FU(INTERV+2)=5000.
000154      C      FA(INTERV+2)=5000.
000155      C      T(INTERV+2)=10.

000156      C      CALL NAMPLT
000157      C      CALL PAUPLO

000160      C      CALL AXIS1(0.,0.,12H0DISPLACEMENT,12,10.0,90.0,D(INTERV+1),0(INTERV
1*2),10.)
000175      C      CALL AXIS1(0.,0.,4HTIME,-4,XLEN+0.,T(INTERV+1),T(INTERV+2),10.)
000212      C      CALL LINE(T,D,INTERV,1,0,0)
000216      C      CALL PLOT(XLEN+4,0+0.,-3)

000223      C      CALL AXIS1(0.,0.,BHVELOCITY,8+10.,+90.,V(INTERV+1),V(INTERV+2),10.)
000240      C      CALL AXIS1(0.,0.,4HTIME,-4,XLEN+0.,T(INTERV+1),T(INTERV+2),10.)
000255      C      CALL LINE(T,V,INTERV,1,0,0)
000261      C      CALL PLOT(XLEN+4,0+0.,-3)

000266      C      CALL AXIS1(0.,0.,6HFORCES,6,10.,+90.,FU(INTERV+1),
1FU(INTERV+2),10.)
000303      C      CALL AXIS1(0.,0.,4HTIME,-4,XLEN+0.,T(INTERV+1),T(INTERV+2),10.)
000320      C      CALL LINE(T,FU,INTERV,1,0,0)
000324      C      CALL LINE(T,FA,INTERV+1,0,0)
000330      C      CALL PLOT(XLEN+4,0+0.,-3)

000335      C      10 CONTINUE
000337      C      CALL ENDPLT
000340      C      STOP
000342      C      END

```

D-3 and D-4

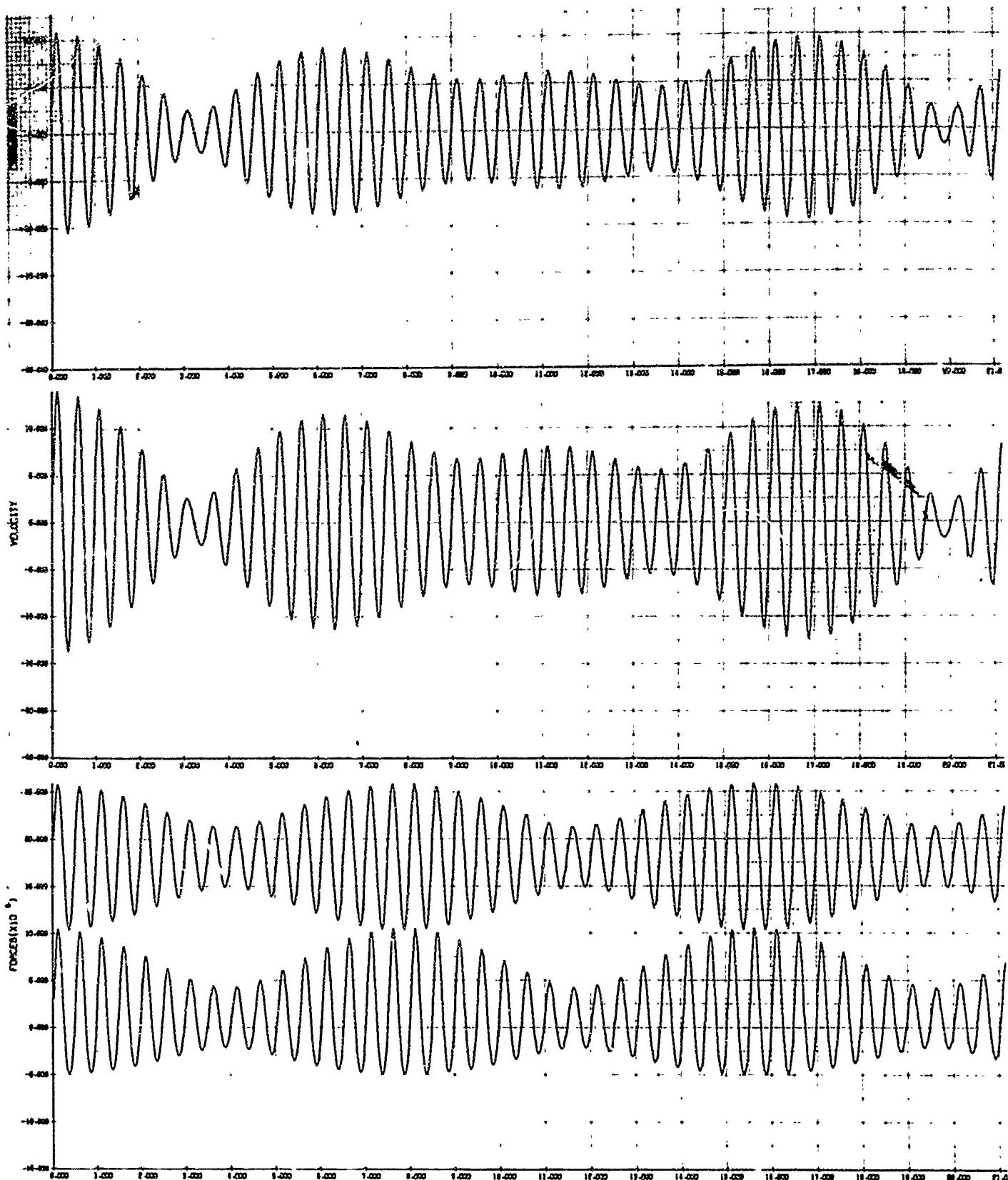
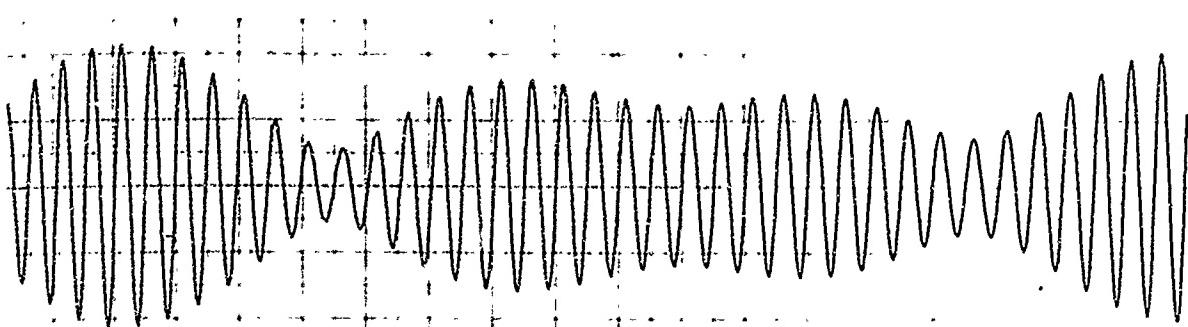
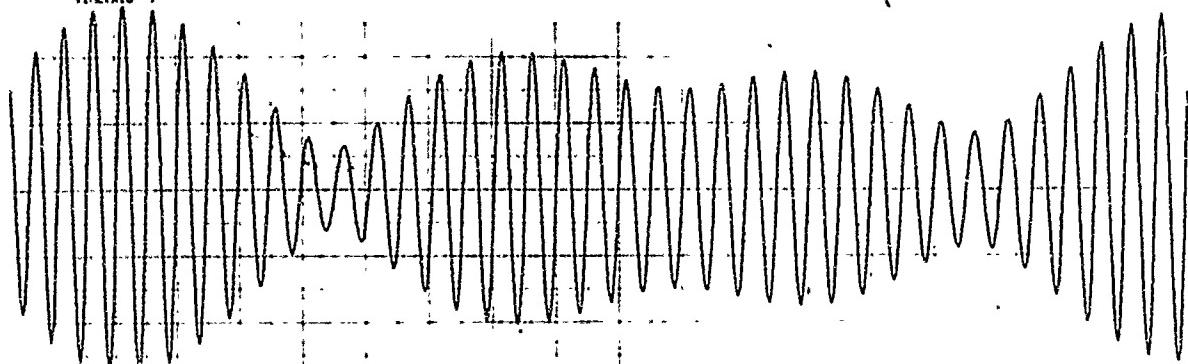


FIGURE D-1 SHIP-TO-SEA RELATIVE MOTIONS AND CABLE LOADS FOR ASR-13  
STERN DEPLOYMENT PATH  
BATTELLE MEMORIAL INSTITUTE - COLUMBUS LABORATORIES

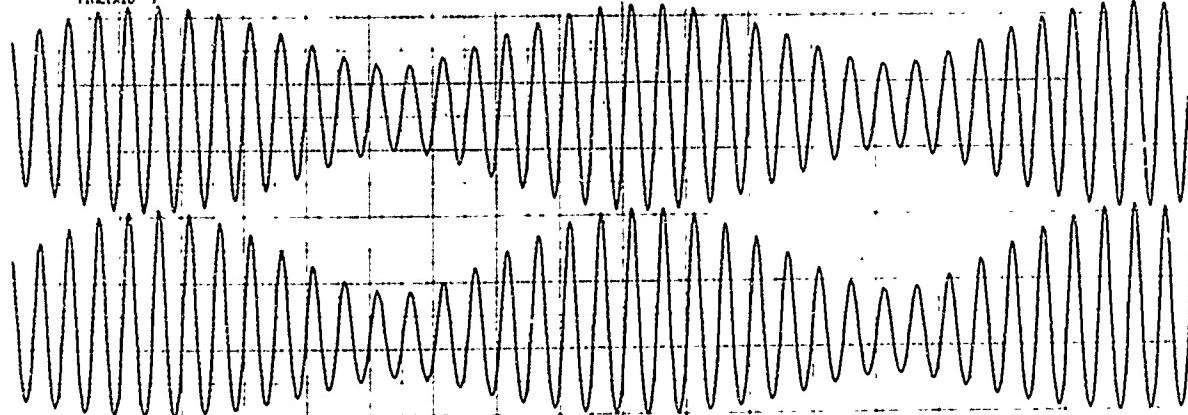
A



26.000 28.000 30.000 32.000 34.000 36.000 38.000 40.000  
TIME(X10<sup>-1</sup>)



26.000 28.000 30.000 32.000 34.000 36.000 38.000 40.000  
TIME(X10<sup>-1</sup>)



26.000 28.000 30.000 32.000 34.000 36.000 38.000 40.000  
TIME(X10<sup>-1</sup>)

B

D-5 and D-6

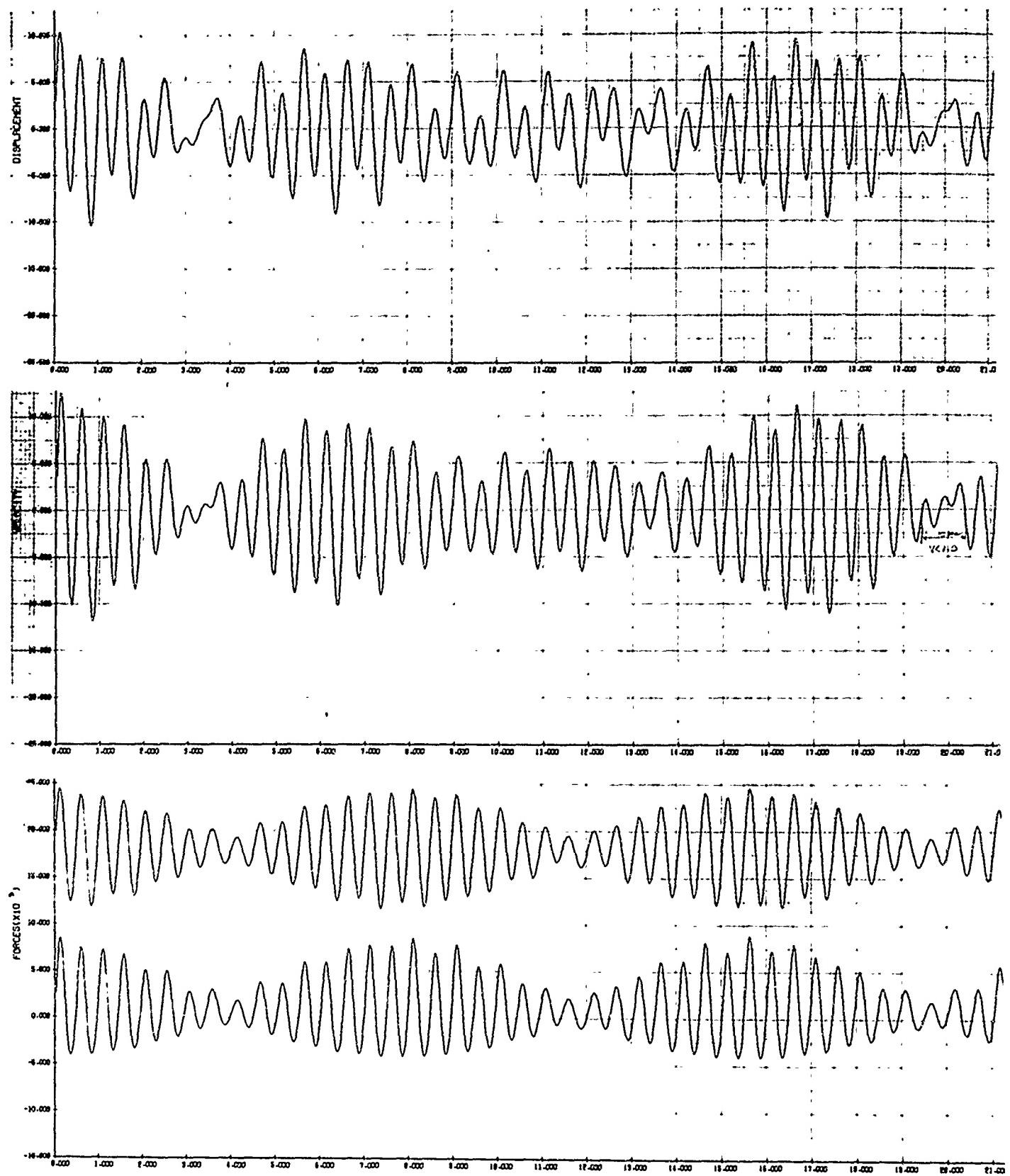
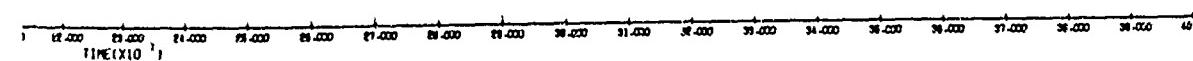
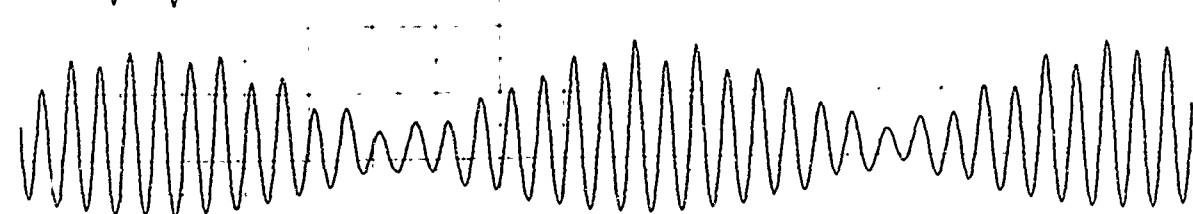
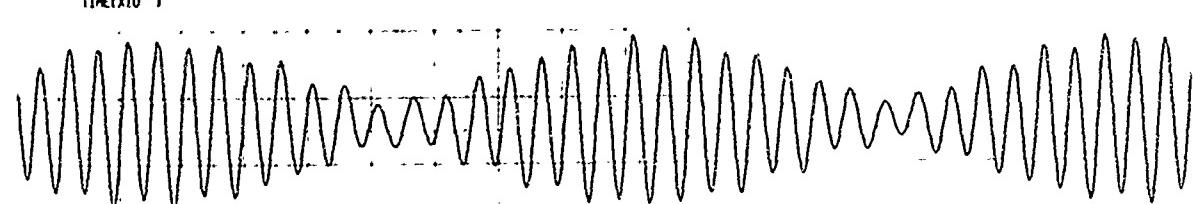
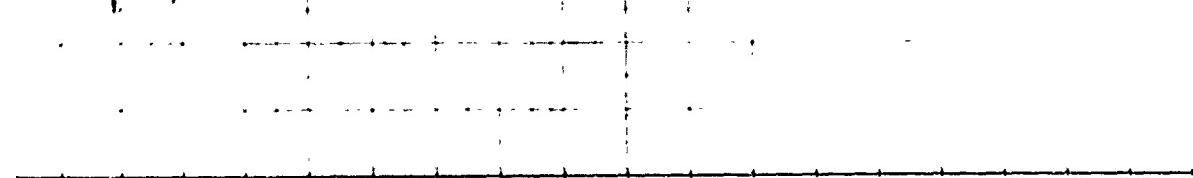
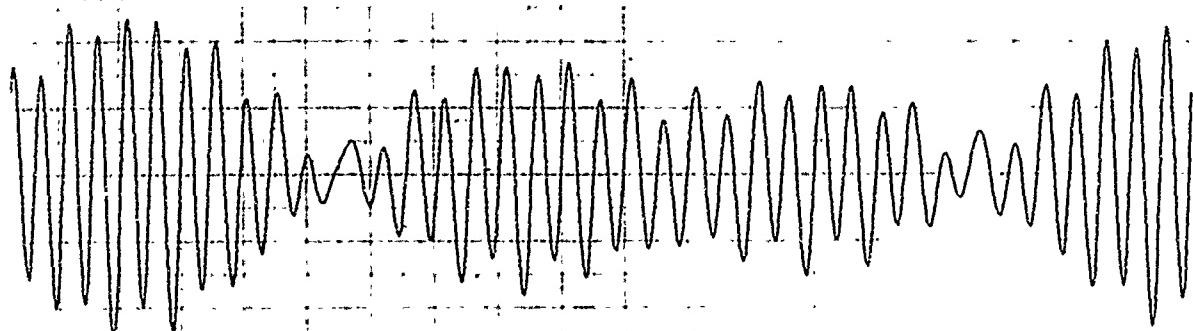
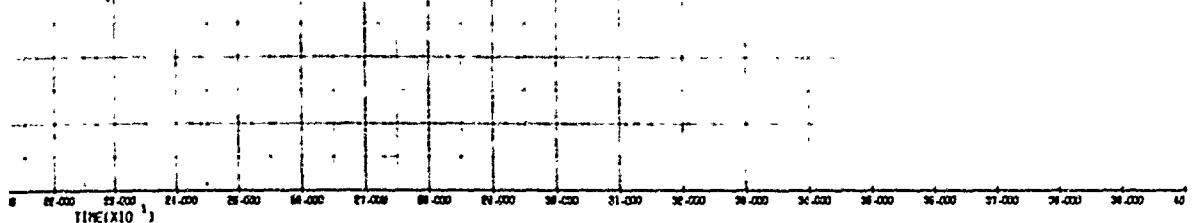
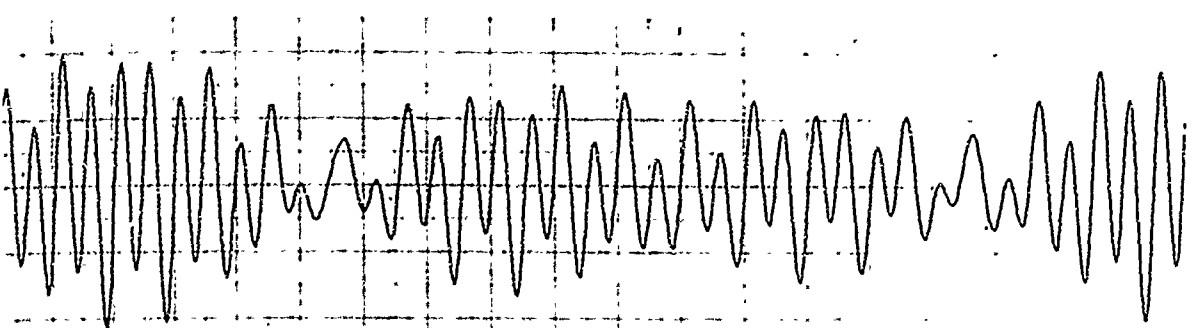


FIGURE D-2. SHIP-TO-SEA RELATIVE MOTIONS AND CABLE LOADS FOR ASR-13  
SIDE DEPLOYMENT PATH  
BATTELLE MEMORIAL INSTITUTE - COLUMBUS LABORATORIES

A



B

D-7 and D-8

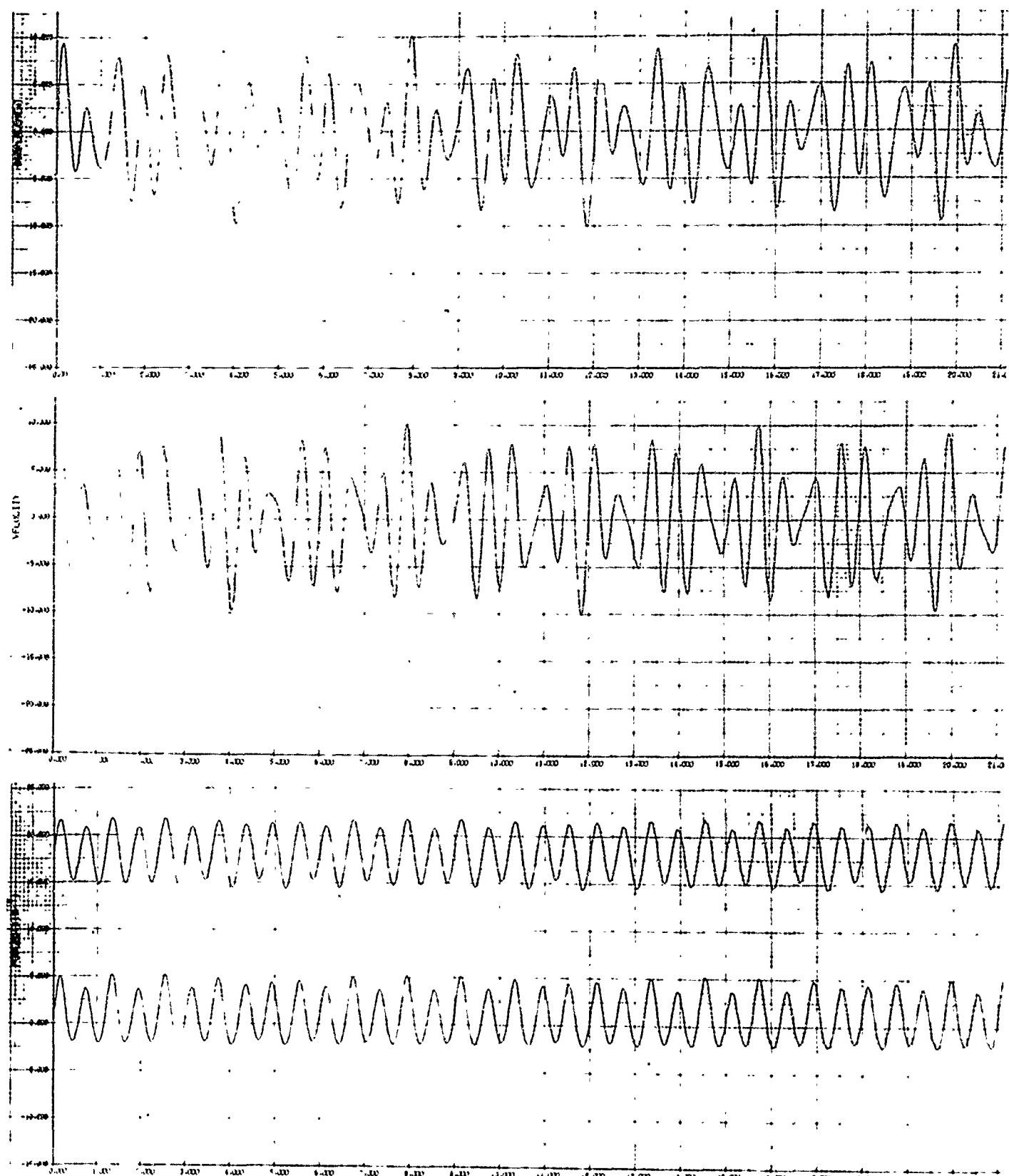
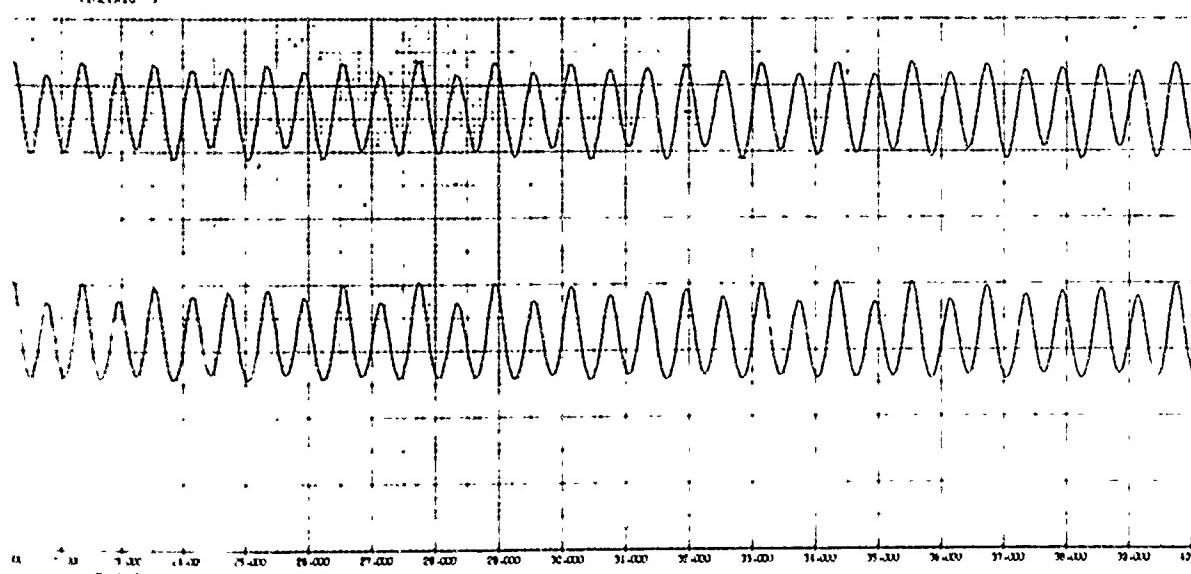
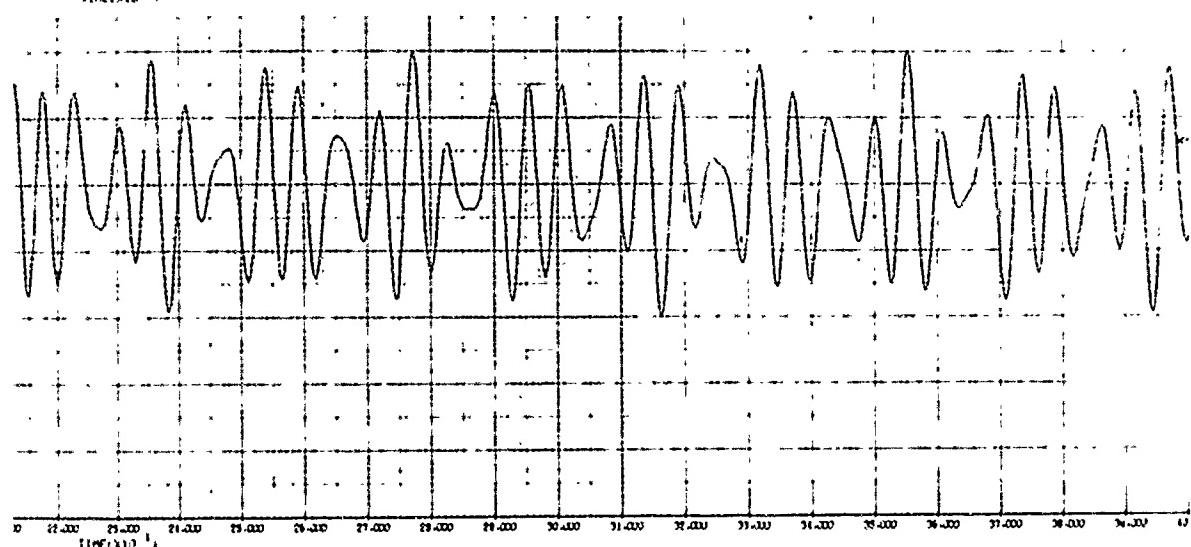
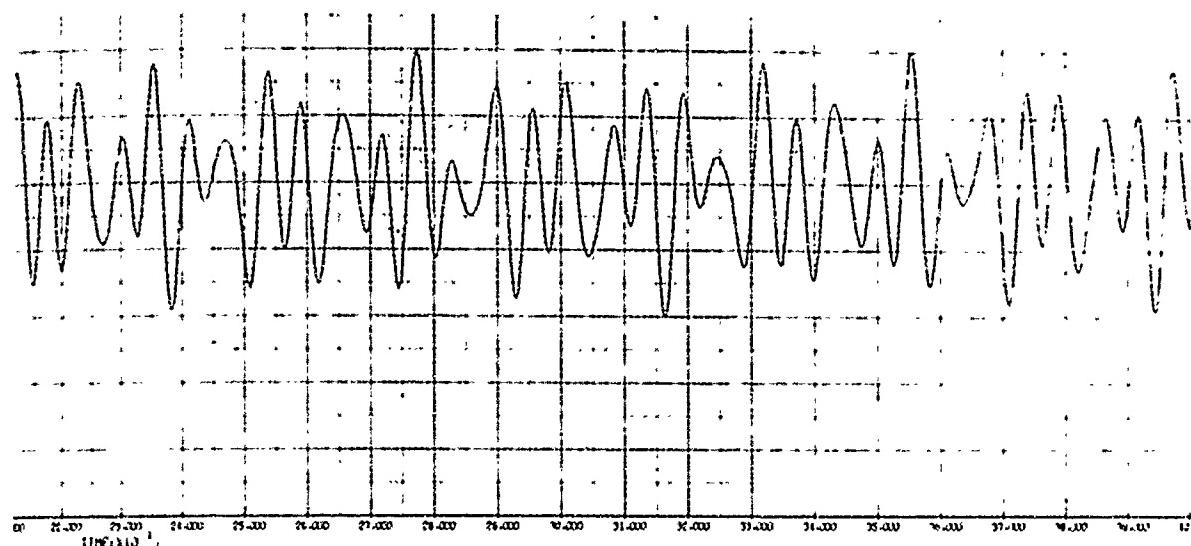


FIGURE D-3. SHIP-TO-SEA RELATIVE MOTIONS AND CABLE LOADS FOR ATS  
SIDE DEPLOYMENT PATH

BATTELLE MEMORIAL INSTITUTE - COLUMBUS LABORATORIES

A



L

D-9 and D-10

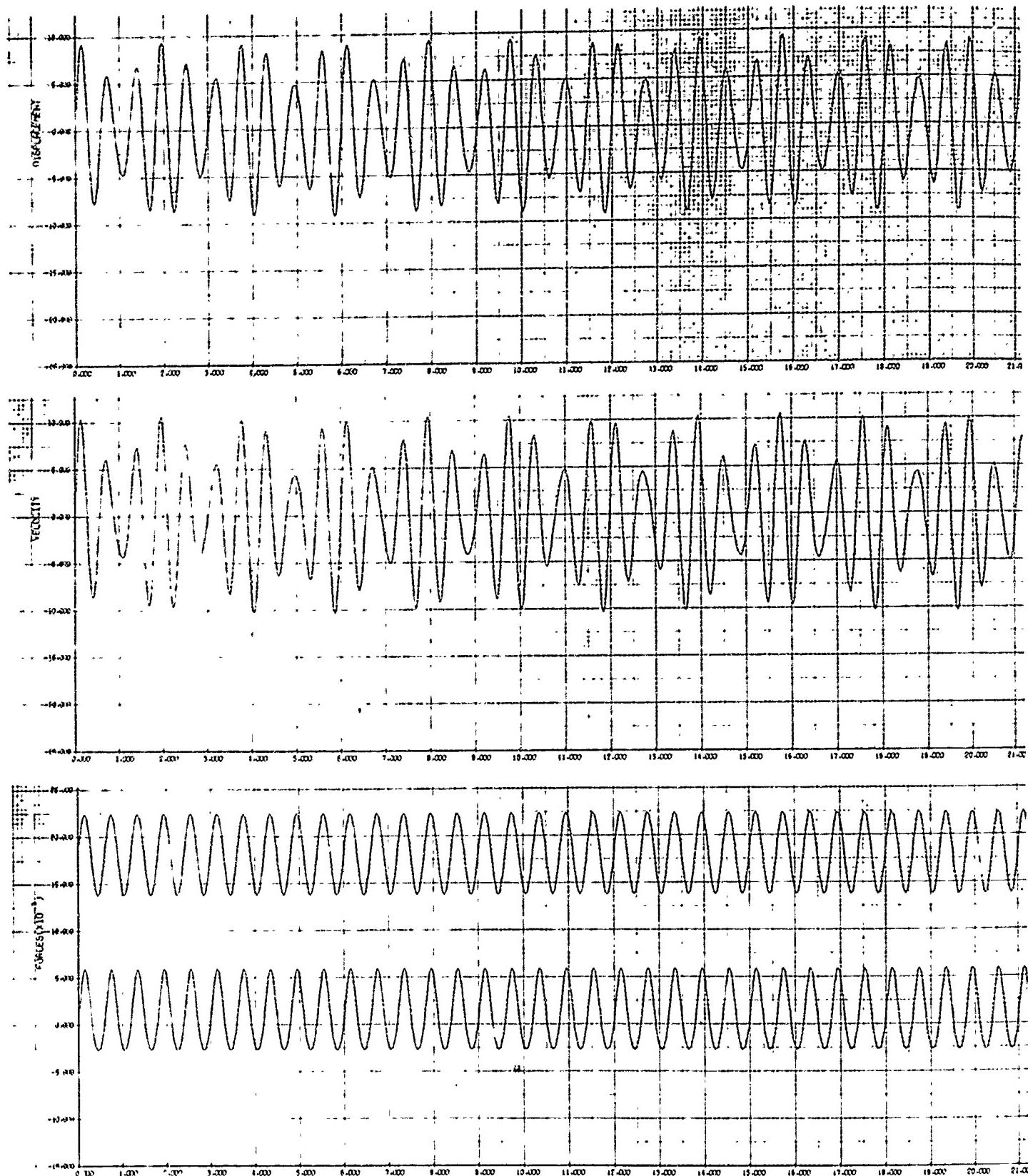
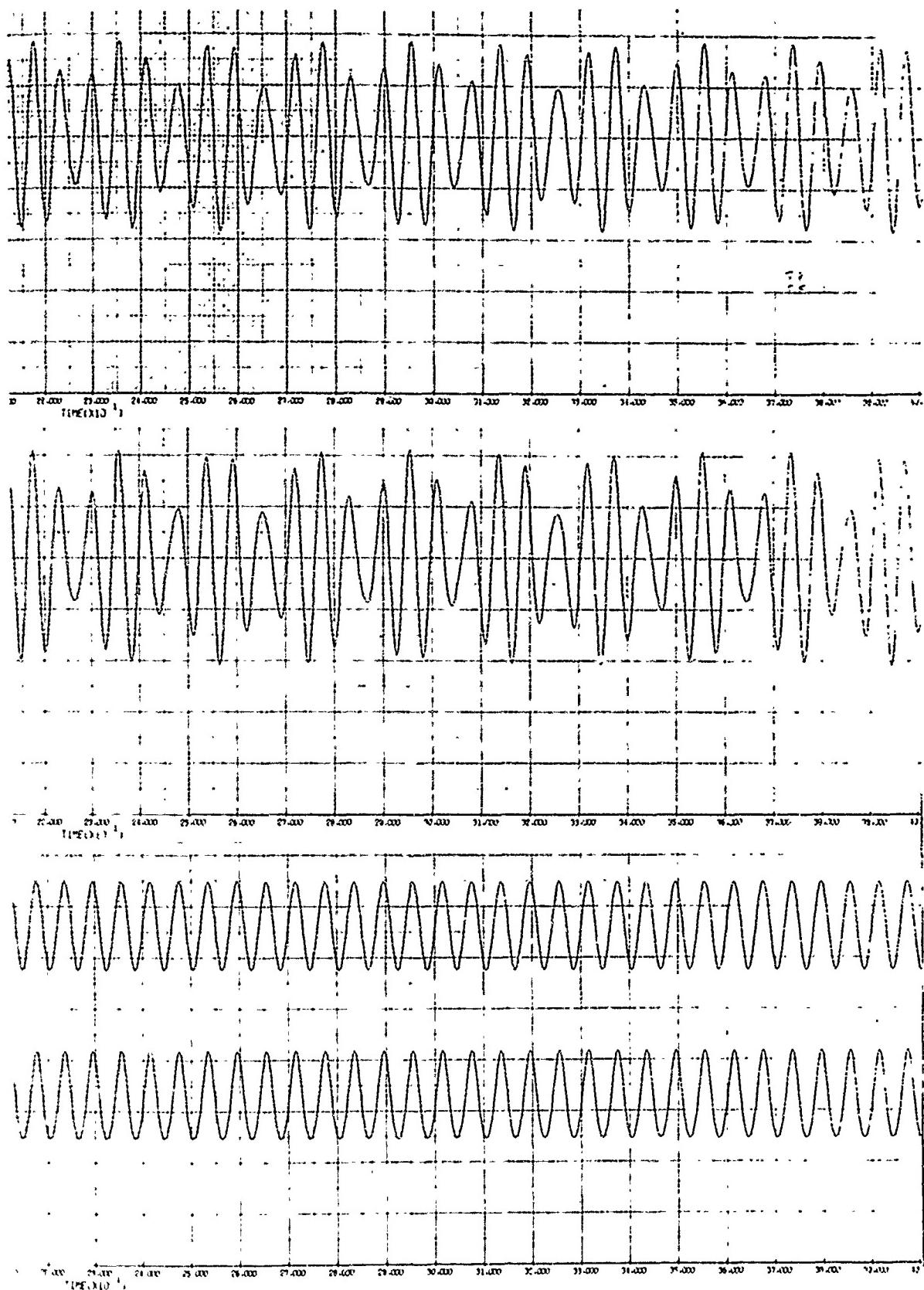


FIGURE D-4. SHIP-TO-SEA RELATIVE MOTIONS AND CABLE LOADS FOR ATS  
STERN DEPLOYMENT PATH  
BATTELLE MEMORIAL INSTITUTE - COLUMBUS LABORATORIES

A



B

## APPENDIX E

SYSTEM WEIGHTS, AND MOMENTS ABOUT KEELHandling System: A-Frame, Ship: ASR-13

<u>Item</u>	<u>Moment Arm, ft</u>	<u>Weight, lb</u>	<u>Moment, ft-lb</u>
1 A-Frame	38	3,350	127,300
2 Pendant	49	1,200	58,800
3 Sheave and Sheave Stand (2)	29	750	21,750
	28.5	750	21,375
4 Hydraulic Cylinders	29.2	3,000	87,600
5 Motor and Pump for Cylinder	28.0	1,500	42,000
6 Constant-Tension Winch	27.8	24,000	667,200
7 Control cab	29.5	1,000	29,500
Total		36,600	1,055,525

Handling System: Articulating Telescoping Crane, Ship: ASR-13

<u>Item</u>	<u>Moment Arm, ft</u>	<u>Weight, lb</u>	<u>Moment, ft-lb</u>
1 Crane	28	56,800	1,590,400
Total		56,800	1,590,400

Handling System: Four-Tugger Winch-Boom, Ship: ASR-13

<u>Item</u>	<u>Moment Arm, ft</u>	<u>Weight, lb</u>	<u>Moment, ft-lb</u>
1 Booms (2)	30.8	1,260	38,808
	31	1,260	39,060
2 Booms (2)	36.3	2,400	87,120
	37.4	2,400	89,760
3 Winches (4)	25.5	500	12,750
	26.5	500	13,250
	27.4	500	13,700
	27	500	13,500
4 Hydraulics (1)	27.5	2,400	66,000
Total		11,720	373,948

Handling System: A-Frame on Rails, Ship: ATS-1

<u>Item</u>	<u>Moment, Arm, ft</u>	<u>Weight, lb</u>	<u>Moment, ft-lb</u>
1 Rails	26.8	10,000	268,000
2 Main Carriage	27.7	10,000	277,000
3 Wheels	26.3	1,000	26,300
4 Hydraulic Cylinders	31.7	3,000	95,000
5 A-Frame	37.7	3,000	113,100
6 Pendant	43	1,200	51,600
7 Motor and Pump for Cylinders	29	1,000	29,000
8 Winch (Constant tension)	29.8	24,000	715,200
9 Winch sheaves	28.2	1,000	28,200
10 Control cab	29.7	1,000	29,700
Total		55,200	1,633,100

Handling System: Articulating Telescoping Crane, Ship: ATS-1

<u>Item</u>	<u>Moment Arm, ft</u>	<u>Weight, lb</u>	<u>Moment, ft-lb</u>
1 Crane	29.7	56,800	1,686,960
Total		56,800	1,686,960

## APPENDIX F

SYSTEM ENVELOPE VOLUMESHandling System: A-Frame, Ship: ASR-13

<u>Item</u>	<u>Envelope Size, ft</u>	<u>Envelope Volume, cu ft</u>
A-Frame	30 x 2 x 2	120
Pendant	12 x 4 x 3	144
Sheave and sheave stand, hydraulic cylinders	8 x 4 x 4	128
Control cab, motor and pump for cylinders	8-1/2 x 3 x 6-1/2	165.75
Constant-tension winch	10 x 9 x 8-1/2	765
Total envelope volume	--	<u>1322.75</u>
Longest envelope dimension	30	--

Handling System: Articulated Telescoping Crane, Ship: ASR-13

<u>Item</u>	<u>Envelope Size, ft</u>	<u>Envelope Volume, cu ft</u>
Crane body	13 x 11 x 6-1/2	929.5
Main boom	15 x 4 x 3	180
Extension cylinder with attachment	16 x 2-1/2 x 2-1/2	100
Total envelope volume	--	<u>1209.5</u>
Longest envelope dimension	16	--

Handling System: Four-Tugger Winch-Boom, Ship: ASR-1/2

<u>Item</u>	<u>Envelope Size, ft</u>	<u>Envelope Volume, cu ft</u>
Booms (2)	18 x 2-1/2 x 1	90
Boom (2)	27-1/2 x 2-1/2 x 1	137.5
Winches (4)	2 x 2 x 3	48
Hydraulic Support	6 x 4 x 4	96
Total envelope volume	--	<u>371.5</u>
Longest envelope dimension	27.5	--

Handling System: A-Frame on Rails, Ship: ATS-1

<u>Item</u>	<u>Envelope Size, ft</u>	<u>Envelope Volume, cu ft</u>
Rails	40 x 1 x 2	80
Main carriage		
Wheels		
Hydraulic cylinders	22 x 19 x 3	1250
A-Frame		
Pendant		
Winch sheaves		
Constant-tension winch	10 x 9 x 9	810
Control cab motor and pump for cylinders	8-1/2 x 3 x 6-1/2	165.75
Total envelope volume	--	<u>2305.75</u>
Longest envelope dimension	40	

Handling System: Articulated Telescoping Crane, Ship: ATS-1

<u>Item</u>	<u>Envelope Size, ft</u>	<u>Envelope Volume, cu ft</u>
Crane body	13 x 11 x 6-1/2	929.5
Main boom	15 x 4 x 3	180
Extension cylinder with attachments	16 x 2-1/2 x 2-1/2	100
Total envelope volume	--	<u>1209.5</u>
Longest envelope dimension	16	--

## APPENDIX G

SYSTEM OPERATION SCENARIOSTABLE G-1. OPERATION SCENARIO: HANDLING SYSTEM - A-FRAME; SHIP,  
ASR-13

Operation Steps	Man Steps				
	Operator in Cab	Diver 1	Diver 2	Tender 1	Tender 2
<u>Deployment: PTC over EL</u>					
1. SPCC put over pendant saddle				X	X
2. Auxiliary cable connected to PTC				X	
3. PTC pulled against automatic latch	X				
4. A-frame powered "over-center" by hydraulic cylinders	X				
5. A-frame lowered into water by constant-tension winch	X				
6. Automatic latch released	X				
7. PTC lowered 20 feet	X				
8. Diver pulls SPCC off pendant saddle		X			
9. Diver unhooks auxiliary cable		X			
10. PTC lowered to work site by SPCC	X				
11. A-frame pulled "over-center" by constant-tension winch	X				
12. A-frame powered down by hydraulic cylinders	X				
<u>Recovery: PTC on SPCC, 30 Feet Below Surface</u>					
1. A-frame powered over-center by hydraulic cylinders	X				
2. A-frame lowered by constant-tension winch	X				
3. Auxiliary cable lowered to PTC	X				
4. Diver works up auxiliary cable		X			
5. PTC pulled against automatic latch	X				
6. Diver leads SPCC over pendant saddle		X			
7. A-frame with PTC pulled out of sea and over-center by constant-tension winch	X				
8. A-frame with PTC lowered by hydraulic cylinders	X				
9. Automatic latch released	X				
10. PTC lowered onto EL by auxiliary cable	X				
11. Auxiliary cable disconnected				X	
12. SPCC taken off pendant saddle				X	X
Total Man Steps	26	16	4	4	2

TABLE G-2. OPERATION SCENARIO: HANDLING SYSTEM, ARTICULATED TELESCOPING CRANE; SHIP, ASR-13

Operation Steps	Man Steps				
	Operator in Cab	Diver 1	Diver 2	Tender 1	Tender 2
<u>Deployment: PTC over EL</u>					
1. Crane moved from stowage position to EL	X				
2. SPCC put over latch saddle				X	X
3. Auxiliary cable connected to PTC				X	
4. PTC pulled against automatic latch	X				
5. Crane moves PTC to underwater-deployment position	X				
6. Automatic latch released	X				
7. PTC lowered 20 feet	X				
8. Diver pulls SPCC off latch saddle		X			
9. Diver unhooks auxiliary cable		X			
10. PTC lowered to work site by SPCC	X				
11. Crane moved to rest position	X				
<u>Recovery: PTC on SPCC, 30 Feet Below Surface</u>					
1. Crane moved from rest position to underwater-recovery point	X				
2. Auxiliary cable lowered to PTC	X				
3. Diver hooks up auxiliary cable		X			
4. PTC pulled snug to automatic latch (cylinder in damp mode)	X				
5. Diver leads SPCC over latch saddle		X			
6. Crane moves PTC to EL	X				
7. Automatic latch released	X				
8. Auxiliary cable disconnected				X	
9. SPCC taken off latch saddle				X	
10. Crane moved to rest position	X				
Total Man Steps	22	13	4	4	1

TABLE G-3. OPERATION SCENARIO: HANDLING SYSTEM, FOUR-TUGGER WINCH-BOOM; SHIP, ASR-13

Operation Steps	Operator in Cab	Man Steps			
		Diver 1	Diver 2	Tender 1	Tender 2
<u>Deployment: PTC over EL</u>					
1-4. Four-tugger booms lowered from vertical stowage position to deployment position				X	
5-8. Four tugger lines connected to PTC				X	
9. SPCC guided over saddle on ships boom	X			X	
10. Ships hook attached to PTC	X			X	
11. PTC moved from EL to underwater-deployment point	X				
12-15. Four tugger lines disconnected		X			
16. SPCC taken off boom saddle and put on over the side sheave				X	
17. Ships hook disconnected from PTC		X			
18. PTC lowered on SPCC	X				
<u>Recovery: PTC on SPCC, 30 Feet Below Surface</u>					
1. Ships hook connected to PTC	X	X			
2. SPCC guided over saddle on ships boom				X	
3-6. Four tugger lines connected to PTC		X			
7. PTC moved from sea position above EL	X				
8-9. Two block and tackles connected to PTC				X	
10. PTC lowered onto EL	X			X	X
11. SPCC taken off saddle on ships boom	X			X	
12-15. Four tugger lines disconnected				X	
16. Ships hook disconnected				X	
17-21. Four-tugger booms returned to stowage position				X	
Total Man Steps	44	8	10	25	1

TABLE G-4. OPERATION SCENARIO: HANDLING SYSTEM, A-FRAME;  
SHIP, ATS-1

Operation Steps	Man Steps				
	Operator in Cab	Diver 1	Diver 2	Tender 1	Tender 2
<u>Deployment: PTC over EL</u>					
1. A-frame moved from stowage position to EL	X				
2. SPCC put over pendant saddle				X	X
3. Auxiliary cable connected to PTC				X	
4. PTC pulled against automatic latch	X				
5. A-frame slid to deployment position	X				
6. A-frame powered "over-center" by hydraulic cylinders	X				
7. A-frame lowered into water by constant-tension winch	X				
8. Automatic latch released	X				
9. PTC lowered 20 feet	X				
10. Diver pulls SPCC off pendant saddle		X			
11. Diver unhooks auxiliary cable		X			
12. PTC lowered to work site by SPCC	X				
13. A-frame pulled "over-center" by constant-tension winch	X				
14. A-frame powered down by hydraulic cylinders	X				
15. A-frame moved to rest position	X				
<u>Recovery: PTC on SPCC, 30 Feet Below Surface</u>					
1. A-frame slid from rest position to recovery location	X				
2. A-frame powered over-center by hydraulic cylinders	X				
3. A-frame lowered by constant-tension winch	X				
4. Auxiliary cable lowered to PTC	X				
5. Diver hooks up auxiliary cable			X		
6. PTC pulled against automatic latch	X				
7. Diver leads SPCC over pendant saddle			X		
8. A-frame with PTC pulled out of sea and over-center by constant-tension winch	X				
9. A-frame with PTC lowered by hydraulic cylinders	X				
10. A-frame slid over to EL	X				
11. Automatic latch released	X				
12. PTC lowered onto EL by auxiliary cable	X				
13. Auxiliary cable disconnected				X	
14. SPCC taken off pendant saddle				X	X
15. A-frame slid to stowage position	X				
Total Man Steps	32	22	4	4	2

TABLE G-5. OPERATION SCENARIO: HANDLING SYSTEM, ARTICULATED TELESCOPING CRANE; SHIP, ATS-1

Operation Steps	Operator in Cab	Man Steps			
		Diver 1	Diver 2	Tender 1	Tender 2
<u>Deployment: PTC over EL</u>					
1. Crane moved from stowage position to EL	X				
2. SPCC put over latch saddle				X	X
3. Auxiliary cable connected to PTC					X
4. PTC pulled against automatic latch	X				
5. Crane moves PTC to underwater-deployment position	X				
6. Automatic latch released	X				
7. PTC lowered 20 feet	X				
8. Diver pulls SPCC off latch saddle		X			
9. Diver unhooks auxiliary cable		X			
10. PTC lowered to work site by SPCC	X				
11. Crane moved to rest position	X				
<u>Recovery: PTC on SPCC, 30 Feet Below Surface</u>					
1. Crane moved from rest position to underwater-recovery point	X				
2. Auxiliary cable lowered to PTC	X				
3. Diver hooks up auxiliary cable			X		
4. PTC pulled snug to automatic latch (cylinder in damp mode)	X				
5. Diver leads SPCC over latch saddle		X			
6. Crane moves PTC to EL	X				
7. Automatic latch released	X				
8. Auxiliary cable disconnected				X	
9. SPCC taken off latch saddle					X
10. Crane moved to rest position	X				
Total Man Steps	22	13	4	4	1

## H-1 and H-2

## APPENDIX H

TABLE H-1, SYSTEM SAFETY RATINGS

System	Estimated Time <sup>(a)</sup>	Men Used for Deployment and Recovery	Steps Requiring Coordination Between Men	Operator Proximity <sup>(b)</sup>	Exposed Cables <sup>(c)</sup>	Total Safety Rating <sup>(d)</sup>
A-Frame, ASR-13	2	8	2	2	2	16
Articulated Telescoping Crane, ASR-13	1	7	1	1	1	11
Four-Tugger Winch-Boom System, ASR-13	3	7	5	3	3	21
A-Frame on Rails, ATS-1	2	8	2	2	2	16
Articulated Telescoping Crane, ATS-1	1	7	1	1	1	11

(a) Most time = 3; least = 1.

(b) Far = 3; near = 1.

(c) Order only.

(d) Lowest = best.

## APPENDIX I

DETERMINATION OF MINIMUM PULL-OUT VELOCITY

Minimum pull-out velocity is the speed required to pull the PTC completely free of the ocean with no relative wave rise. This speed was graphically determined on the ship-motion computer plots using an iteration process. Each iteration consisted of the following steps:

- (1) Select a pair of points on the displacement-time plot. Determine the maximum (relative ship-to-sea velocity) slope between the two points.
- (2) Determine the maximum-displacement variation between the two points.
- (3) Add the maximum-displacement variation to the vertical height of the PTC. This gives the required pull-out height.
- (4) Determine the required pull-out velocity by dividing the pull-out height by the time between the selected points.
- (5) Compare this required pull-out velocity with the relative ship-to-sea velocity.
- (6) Select another pair of points accordingly until a minimum required pull-out velocity greater than or equal to the maximum relative ship-to-sea velocity is found.

Determination of the minimum pull-out velocity for the handling paths used is shown in Figures I-1, I-2, and I-3.

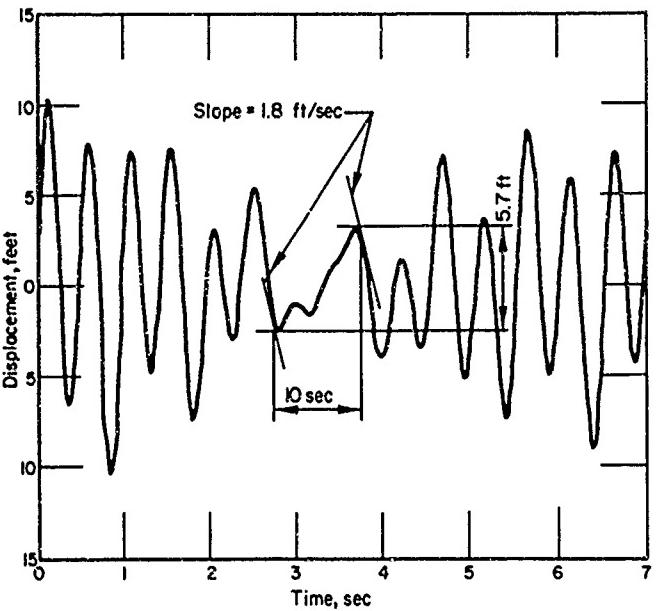


FIGURE I-1. ASR SIDE DEPLOYMENT MINIMUM PULL-OUT VELOCITY

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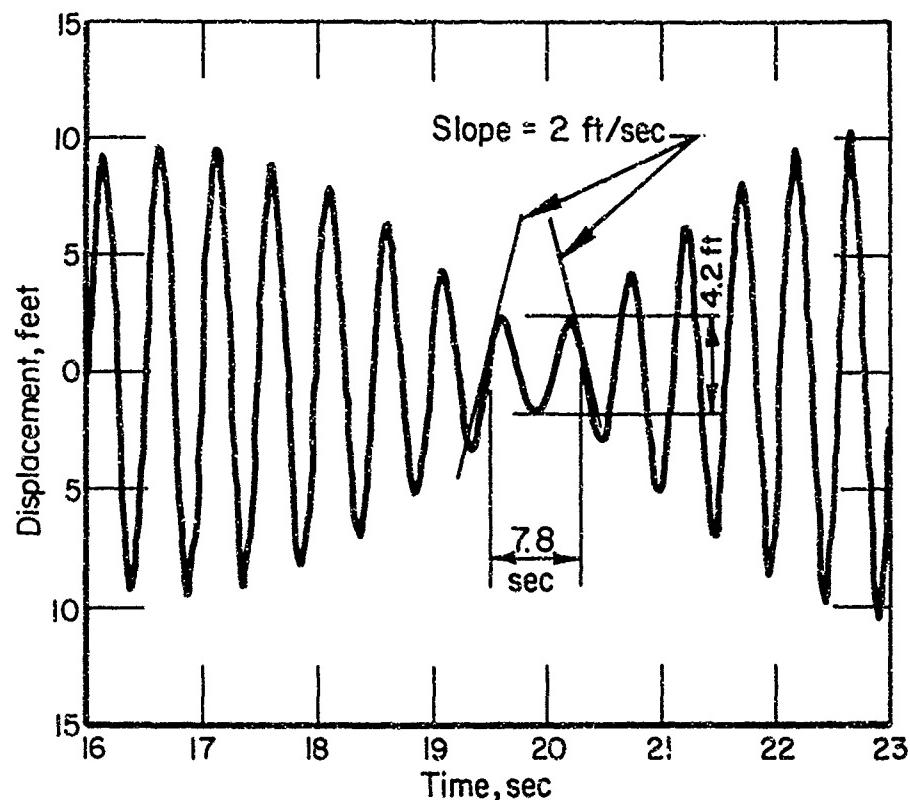


FIGURE I-2. ASR 13 STERN DEPLOYMENT MINIMUM PULL-OUT VELOCITY

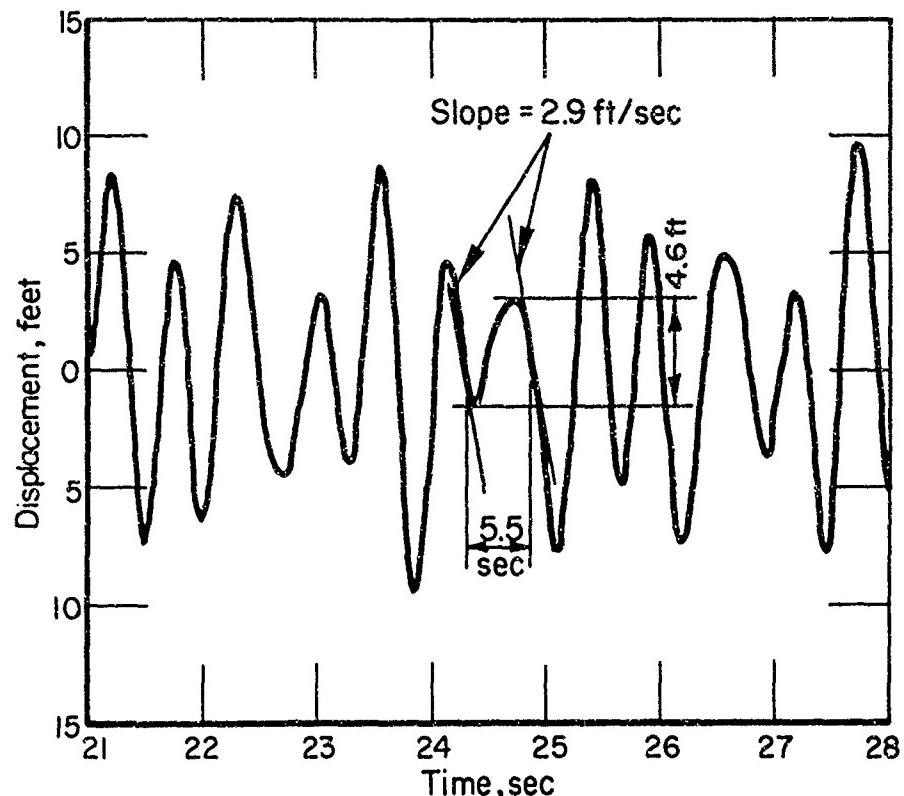


FIGURE I-3. ATS 1 SIDE DEPLOYMENT MINIMUM PULL-OUT VELOCITY  
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## APPENDIX J

APPROXIMATE SYSTEM COST AND DELIVERY TIMEA-Frame ASR-13Hardware

1. A-frame (aluminum)	\$10,000
2. Pendant (aluminum)	3,600
3. Sheave and sheave stand	500
4. Hydraulic cylinders	1,000
5. Motor and pump (engine)	2,500
6. Control cab	1,000
	<u>\$18,600</u>
7. Constant-tension winch	35,000
	<u>\$53,600</u>

6 mos

Development

- A. Design System
  - A-frame, pivots, pendant drive
  - Provide drawings and specifications
- B. Design shipboard modifications, make measurements, modifications drawings and written instructions
- C. Coordinate purchased and outside fab parts inquiries, write installation and operating manual

4 MME	14,000
3 MMD	7,500
	<u>\$21,500</u>

4 mos

Fabrication and Implementation

- A. Coordinate fabrication, assembly schedules, check out and inspection, provide crew training manual

4 MME	<u>\$14,000</u>
-------	-----------------

Total time = 10 months, Total cost = \$89,100

Articulated Telescoping Crane ASR-13Hardware

1. Crane subassembly	\$47,000
2. Base assembly	5,500
3. Latch PTC rotation, etc.	1,500
4. Auxiliary cable winch	9,000
5. Dual-mode cylinder	3,500
6. Control system and hydraulics	4,500
	<u>\$71,000</u>

Development

## A. Design System

Dual-mode cylinder, PTC rotation, winch and crane requirements, subbase, drives  
Provide drawings and specifications, etc.

4 mos

- B. Design shipboard modifications, make measurements, modification drawings, and written instructions
- C. Coordinate with vendors and write detailed operating manual

5 MME	17,500
5 MMD	12,500
	<u>\$30,000</u>

Fabrication and Implementation

6-7\* mos

- A. Coordinate fabrication, assembly schedules, check out and inspection, provide training manual

4 MME	<u>\$ 14,000</u>
-------	------------------

Total time = 10-11 months, Total cost = \$115,000

\*4-5 months lead time on crane.

Four Tugger Winch Boom, ASR-13Hardware

1. 2 booms	\$ 1,500
2. 2 booms	2,500
3. 4 winches	4,000
4. Hydraulics	2,000
	<u>\$10,000</u>

↓  
3 mos  
↓

Development

## Design System

Booms, hydraulics, shipboard modifications,  
make measurements  
Provide drawings, written instructions, and operating manual

3 MME	10,000
2 MMD	5,000
	<u>\$15,000</u>

↓  
2 mos  
↓

Fabrication and Implementation

Fabricate booms, purchase hydraulics and winches,  
supervise shipboard modifications, check out, inspection,  
and training

3 MME	<u>\$10,000</u>
Total time = 5 months, Total cost =	\$35,000

A-Frame on Rails, ATS-1Hardware

Rails	\$ 2,500
Main carriage (aluminum)	10,000
Wheels	500
Hydraulic cylinder (\$500 ea)	1,000
A-frame (aluminum)	10,000
Pendant (aluminum)	3,600
Motor and pump for cylinder (engine)	2,000
Winch sheaves and stands	500
Control cab	1,000
Ball screw and actuator	900
Constant-tension winch	35,000
	<u>\$67,000</u>

Development

6 mos

- A. Design System
  - Rails, drive, A-frame, pendant  
Provide drawings and specs.
- B. Design shipboard modifications, make measurements, modification drawings and written instruction
- C. Coordinate purchased part inquiries and write installation and operating manual

5 MME	17,500
3 MMD	7,500
	<u>\$25,000</u>

Fabrication and Implementation

4 mos

- A. Coordinate fabrication, assembly schedules, check out and inspection, supervise installation and conduct training

4 MME	\$ 15,000
-------	-----------

Total time = 10 months. Total cost = \$107,000

Articulated Telescoping Crane, ATS-1Hardware

1. Crane subassembly	\$ 47,000
2. Base assembly	5,500
3. Latch PTC rotation, etc.	1,500
4. Auxiliary cable winch	9,000
5. Dual-mode cylinder	3,500
6. Control system and hydraulics	4,500
	<u>\$ 71,000</u>

Development

## A. Design System

Dual-mode cylinder, PTC rotation, winch and crane  
requirements, subbase, drives  
Provide drawings and specifications, etc.

4 mos

- B. Design shipboard modifications, make measurements,  
modification drawings and written instructions
- C. Coordinate with vendors and write detailed operating  
manual

5 MME	17,500
5 MMD	12,500
	<u>\$ 30,000</u>

↑  
6-7½ mos ↓

Fabrication and Implementation

- A. Coordinate fabrication, assembly schedules, check out  
and inspection, provide training manual

4 MME	<u>\$14,000</u>
-------	-----------------

Total time = 10-11 months. Total cost =

\$115,000

\*4-5 months lead time on crane.

K-1 and K-2

APPENDIX K

SYSTEM LAYOUT DRAWING

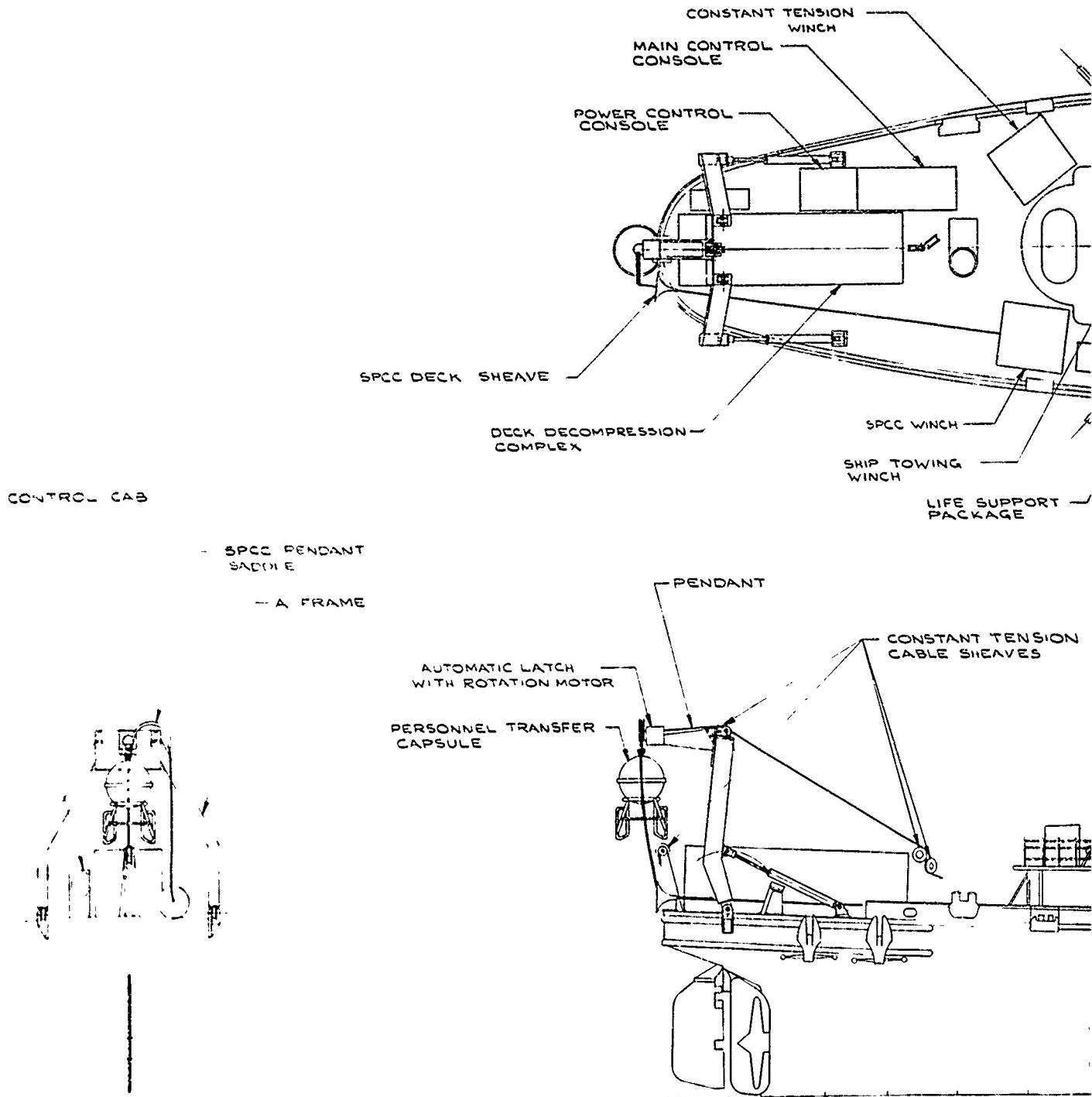
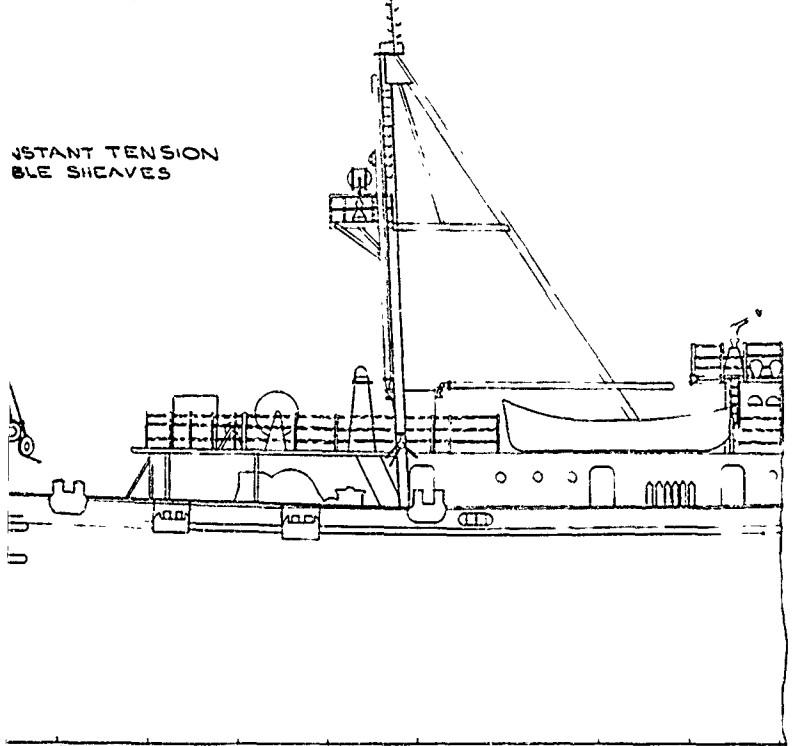
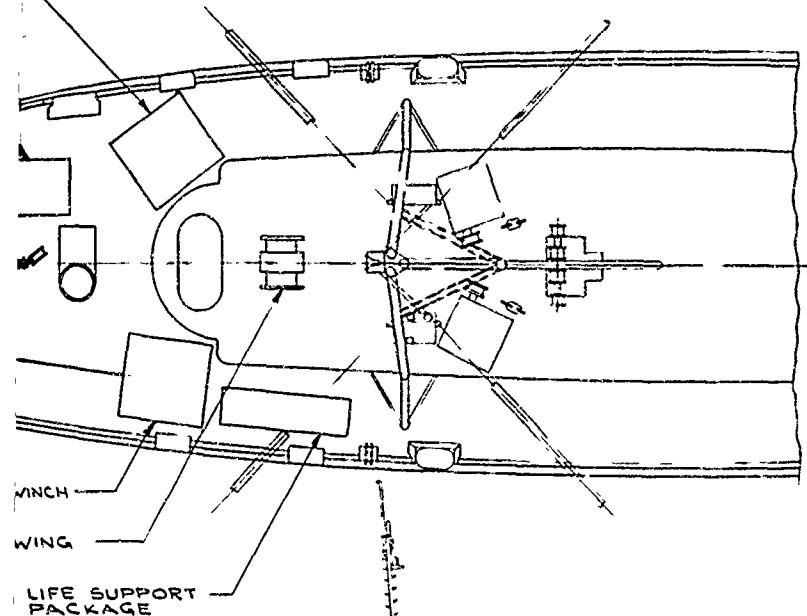


FIGURE K-1. MK I HANDLING A-FRAME ASR-13

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B

K-3 and K-4

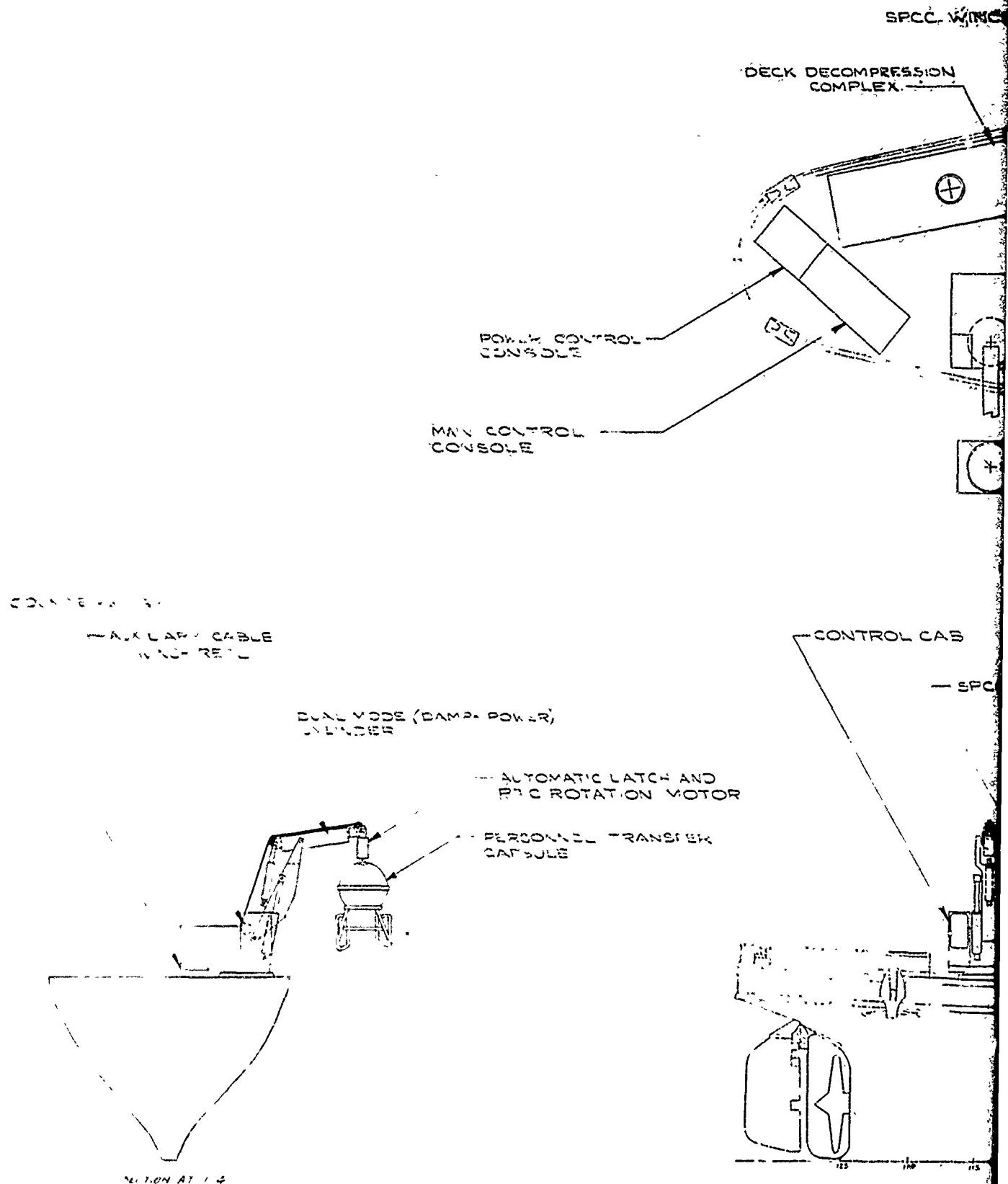
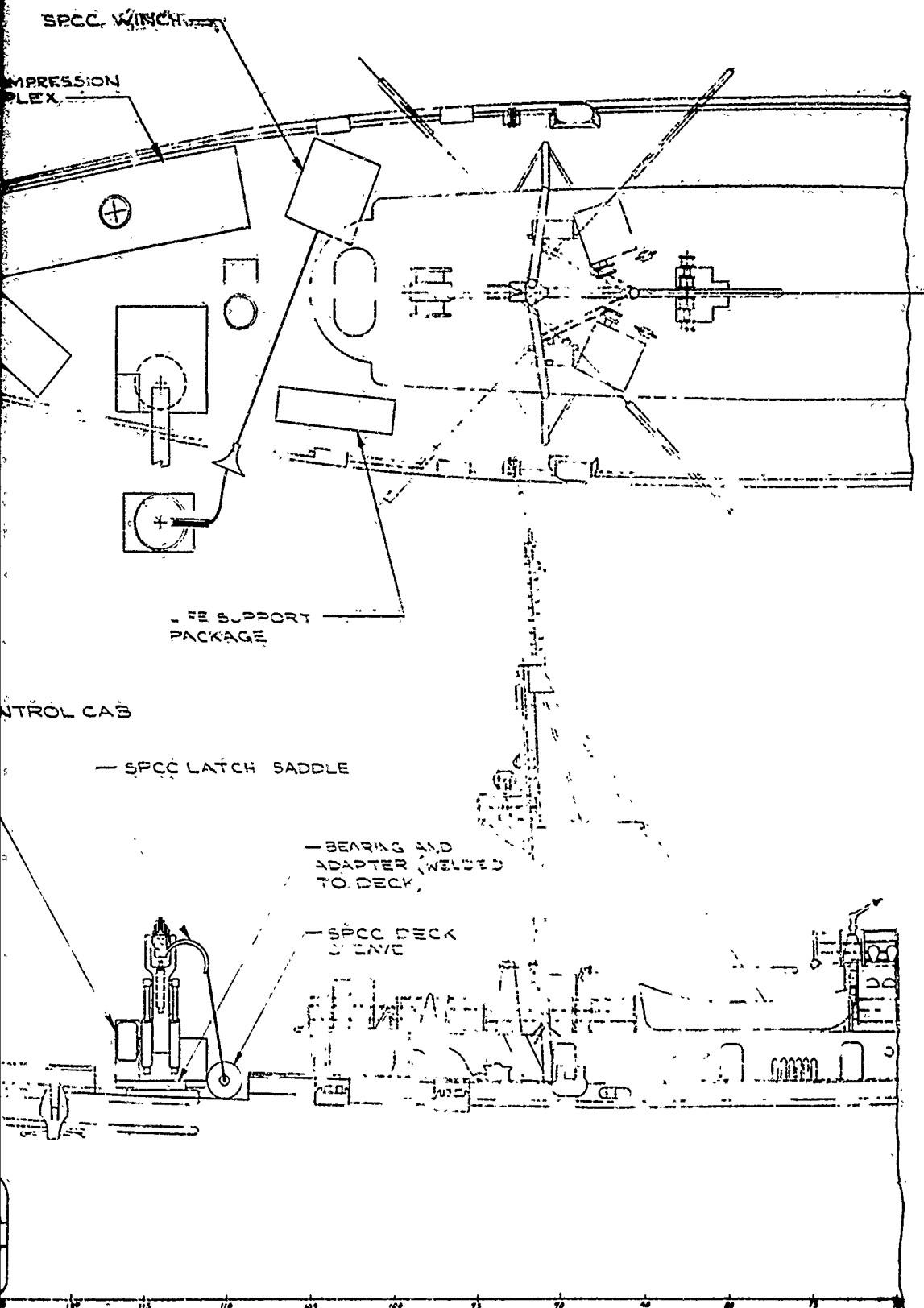


FIGURE K-2. MK I HANDLING ARTICULATED CRANE ASR-13

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A



R

K-5 and K-6

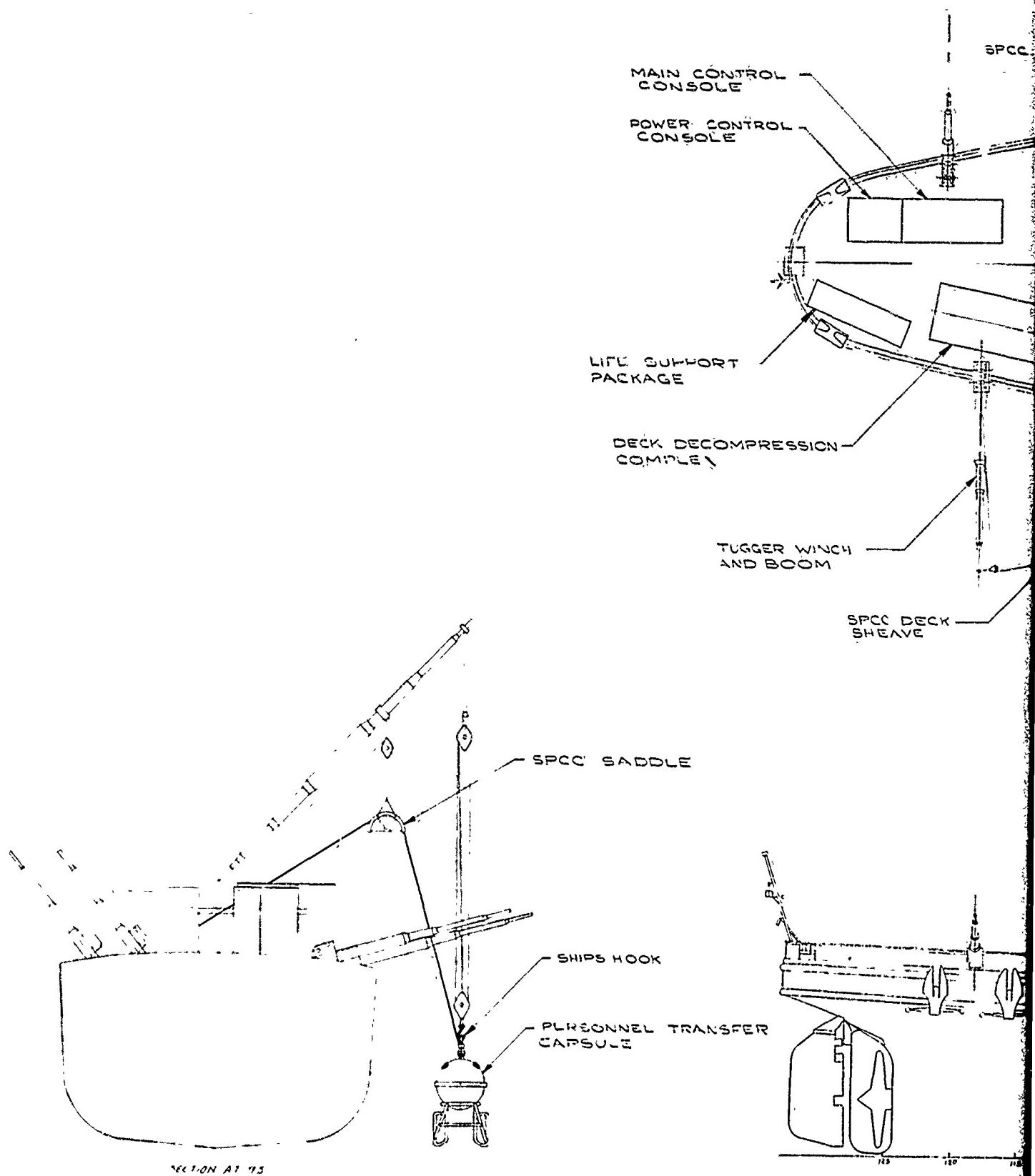
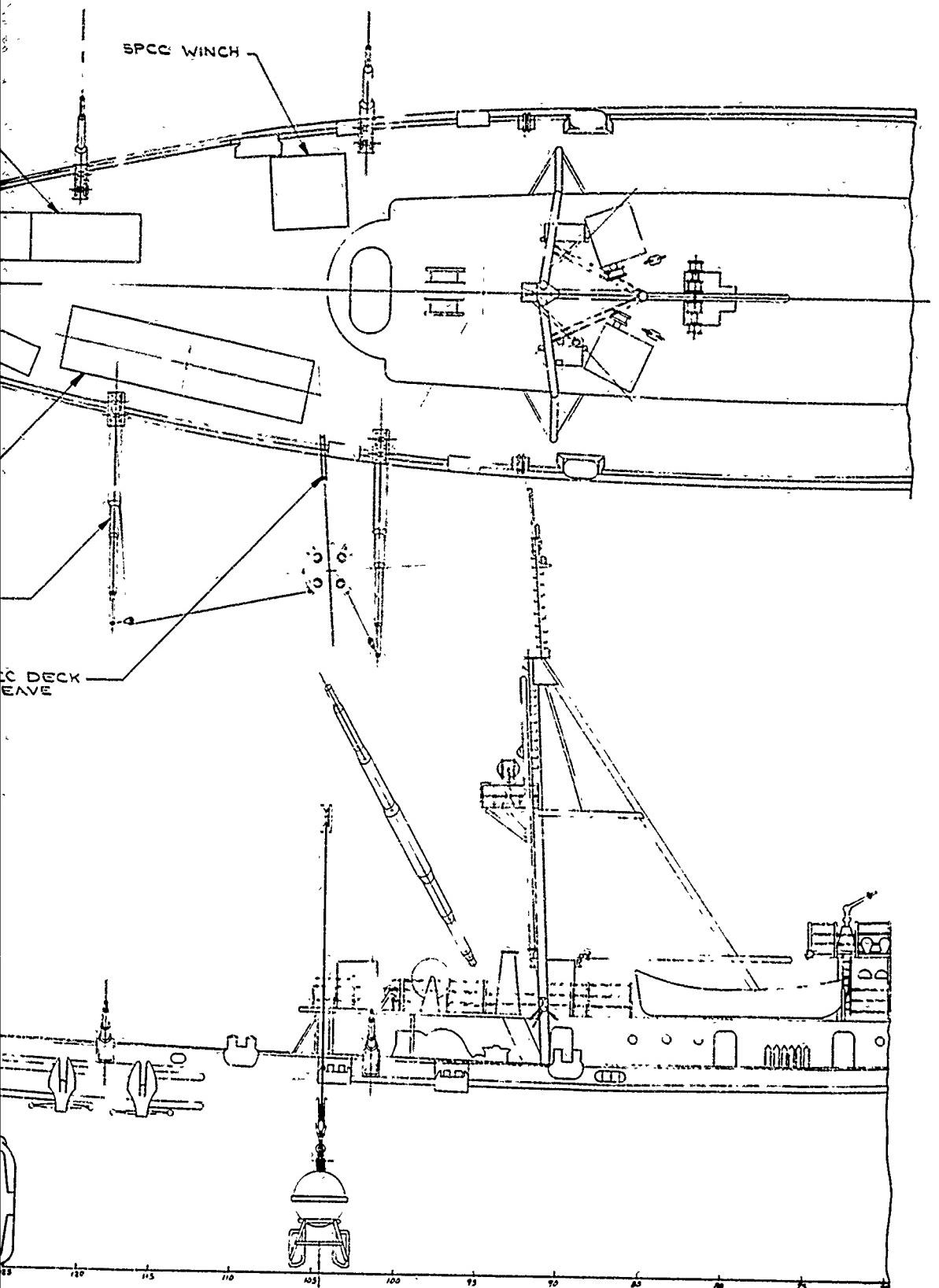


FIGURE K-3. MK I HANDLING FOUR TUGGER BOOMS ASR-13

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A



B

K-7 and K-8

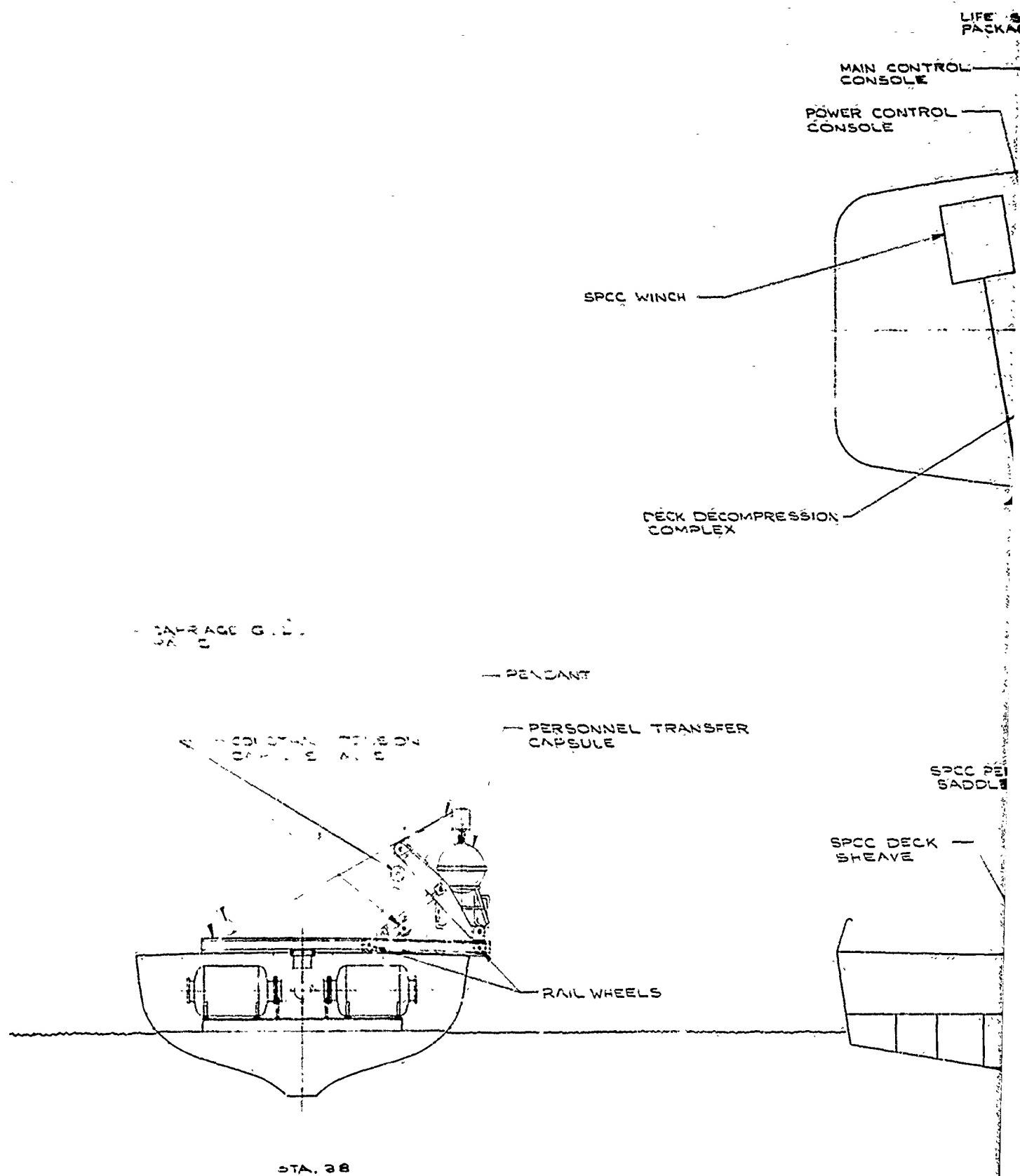
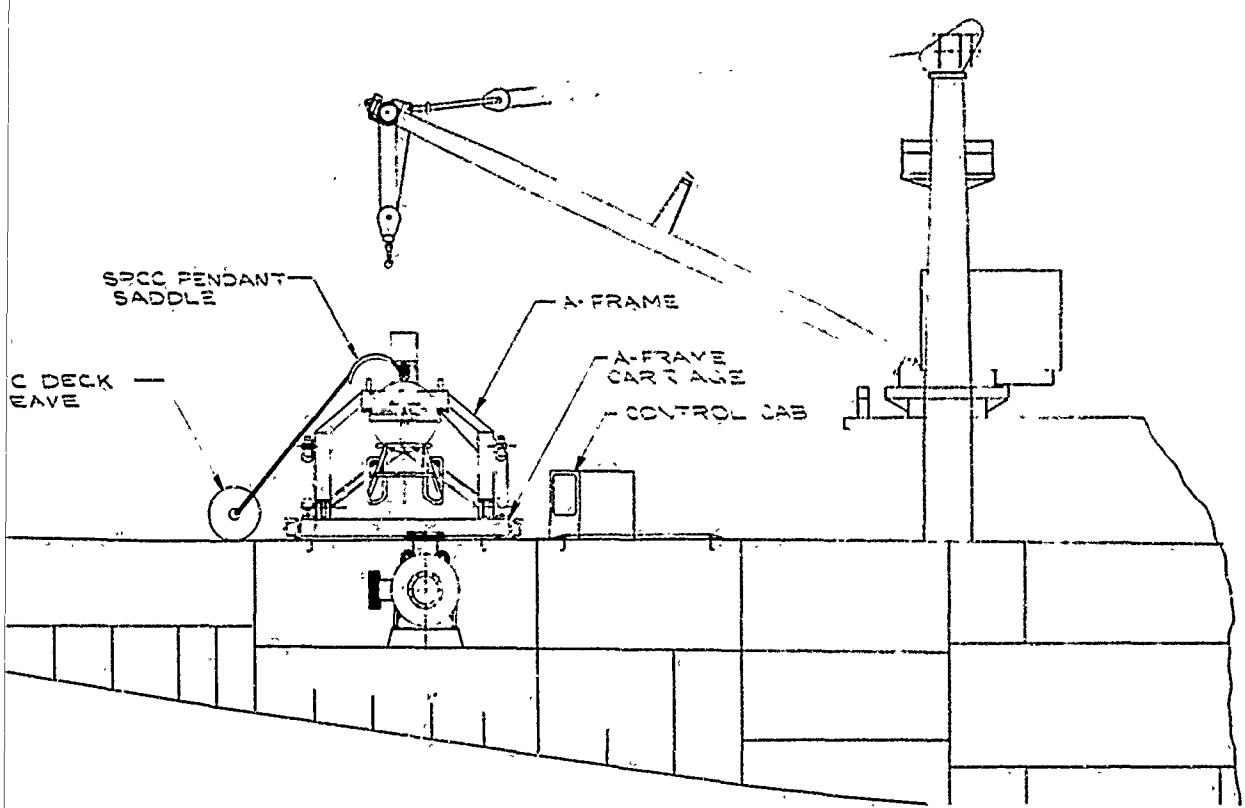
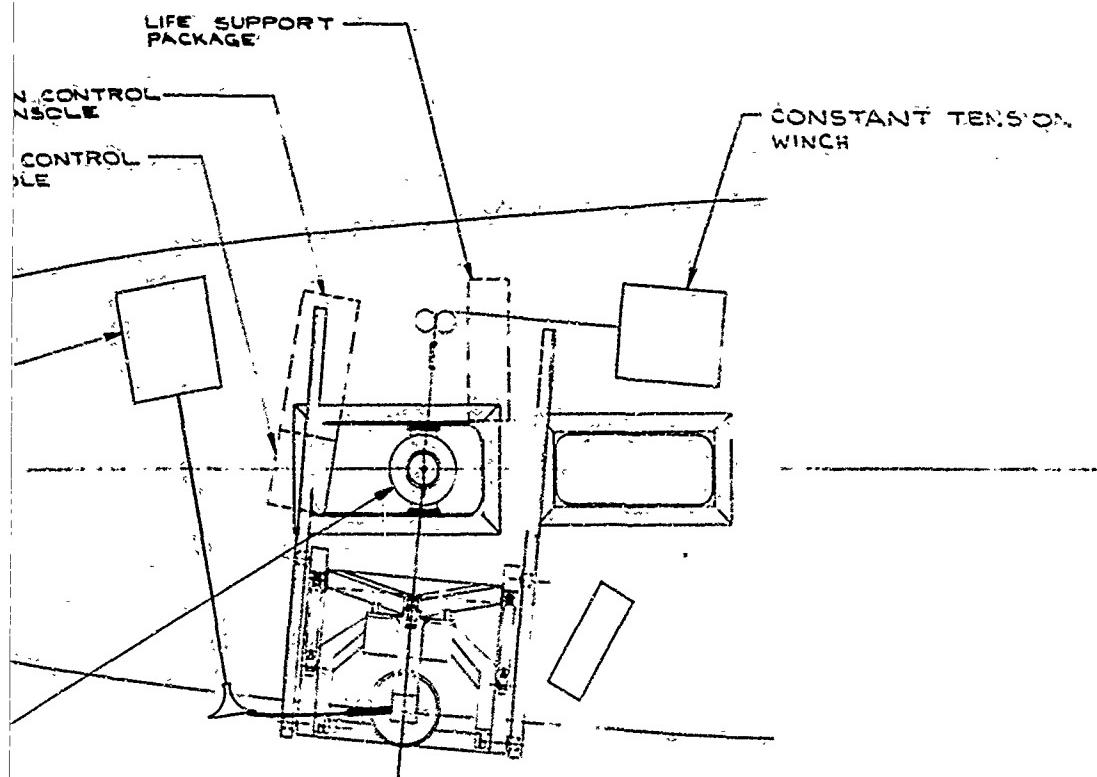


FIGURE K-4. MK I HANDLING A-FRAME ON RAILS ATS-1

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A



(B)

K-9 and K-10

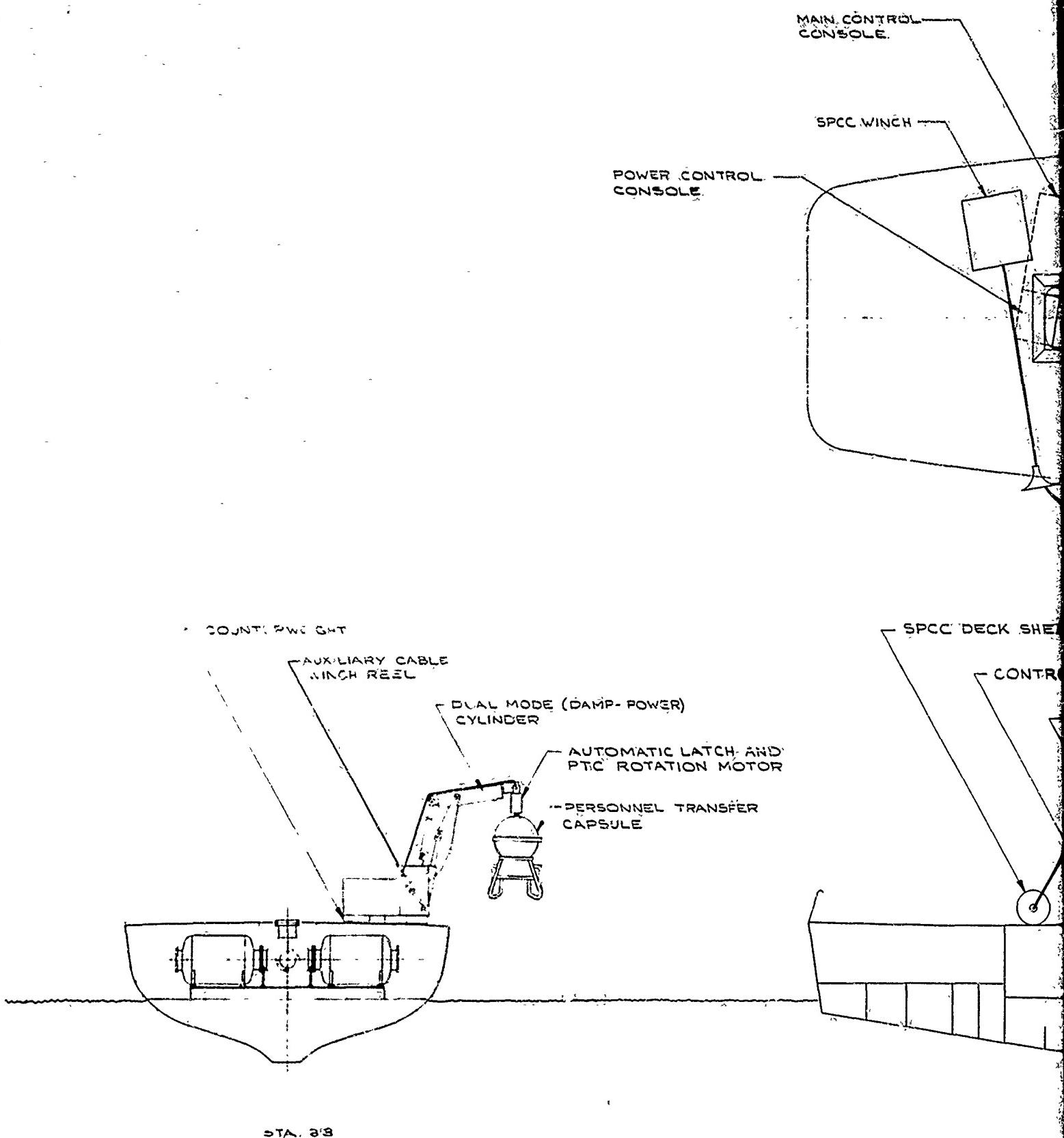
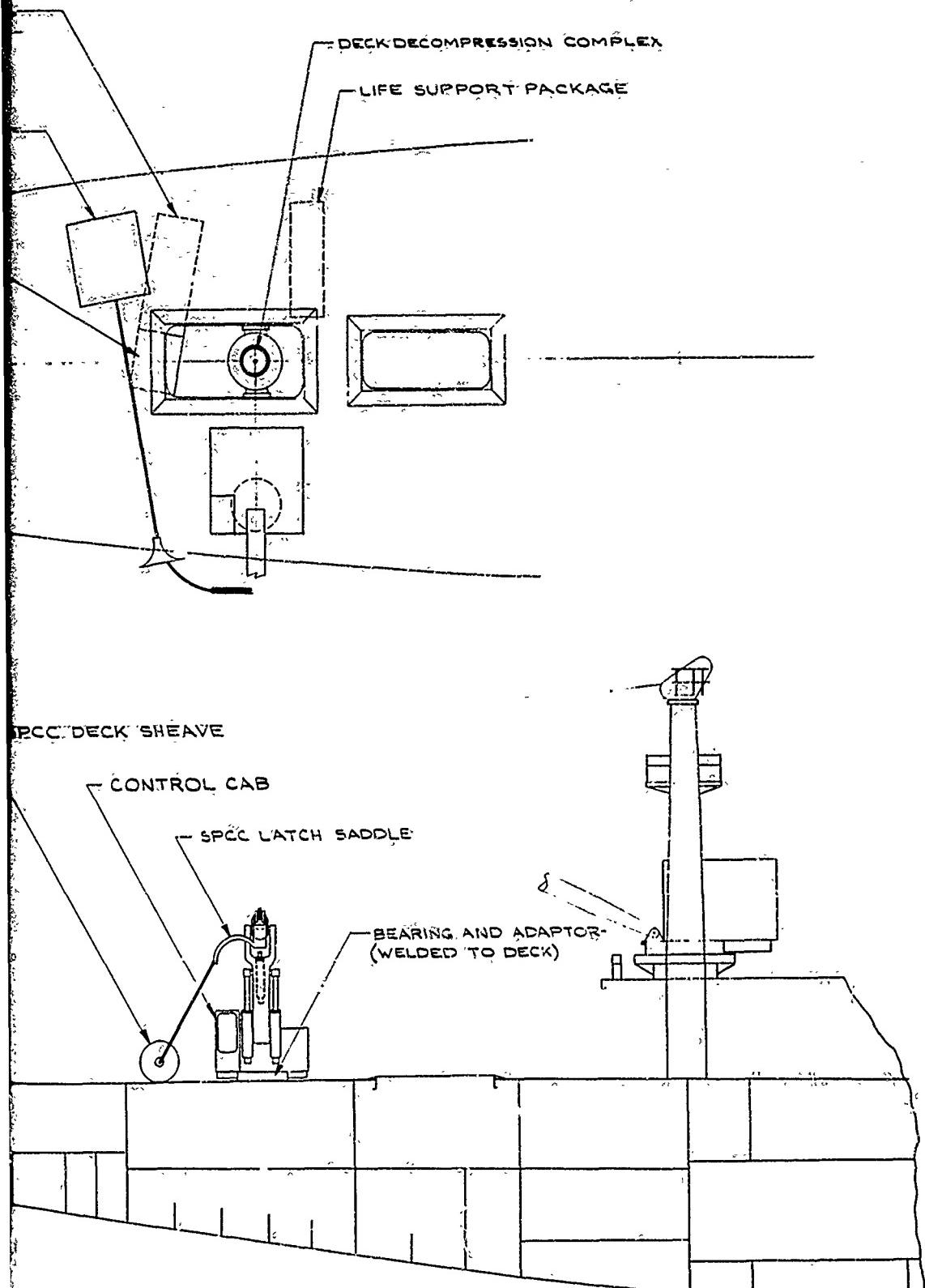


FIGURE K-5. MK I HANDLING ARTICULATED CRANE ATS-1

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## UNCLASSIFIED

## Security Classification

## DOCUMENT CONTROL DATA - R&amp;D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

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4. DESCRIPTIVE NOTES (Type of report and Inclusive dates) Summary Technical Report		
5. AUTHOR(S) (Last name, first name, initial) Doerschuk, David, C. Adkins, David, E. Glasgow, James, S.		
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13. ABSTRACT This report covers selection of an optimal concept for handling the Mark I Deep Dive System's Personnel Transfer Capsule, in a Sea State 3, from ATS, ASR, and ARS Class ships. Included are descriptions of some of the many possible handling system concepts generated by idea conferences and a literature search. The more feasible concepts are analyzed and compared using a set of eleven comparison factors. The optimal system, an articulated telescoping crane, is chosen according to its overall performance on the comparison factors.		

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